INTERN EQUIVALENCY AT
THE OFFICE OF THE PROGRAM MANAGER
XM1 TANK SYSTEMS

AN INTERNSHIP REPORT

BY

Paul Michael Root

Submitted to the College of Engineering
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ABSTRACT

INTERNSHIP EQUIVALENCY AT
THE OFFICE OF THE PROGRAM MANAGER
XM1 TANK SYSTEMS

Paul Michael Root, B. S., United States Military Academy
Master of Science, Stanford University
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This report discusses the author's engineering experiences while a member of the Office of the Program Manager, XM1 Tank Systems, from December 1976 until June 1980. A report on this experience plus twelve additional hours of coursework were substituted for an internship in accordance with requirements established by the College of Engineering.

The experience gained by the author in his assignment can be directly related to the two general objectives of an internship:

1. To demonstrate and enhance his ability to apply both knowledge and technical training by demonstrating an identifiable contribution to the organization in which the intern served.

2. To enable the intern to function in a non-academic

environment in which he will become aware of his employer's approach to the solution of problems, especially those of a non-technical nature.

The author served in the Automotive Branch of the Systems Engineering Division and was the Program Manager's principal representative on all matters concerning the AGT 1500 turbine engine and related systems for the XM1 Tank. Additionally, he was assigned responsibilities in many areas not directly related to the engine. This report discusses some of his major areas of responsibility and his contributions in those areas. Several general observations concerning his experiences are also discussed.

ACKNOWLEDGEMENTS

The author wishes to thank those who assisted and guided him during his assignment to the Office of the Program Manager, XM1 Tank Systems. Particular thanks are due to Mr. Gene Trapp, Mr. Lou Gerback, and especially to LTC Dyson Miller, who taught the author much of what he has learned about program management.

The support of the author's academic committee is also appreciated, especially that of his chairman, Dr. Don E. Bray, who provided great assistance in the waiver of the internship. Dr. Warren Heffington, Dr. Jack Perry, and Dr. Karl Putnam are thanked for the assistance and encouragement they provided to the author. Dr. Lee Carlson is thanked for serving as the College of Engineering Representative, and Mr. Ward Wells is thanked for serving as Graduate College Representative. Special thanks are due to Dean L. S. Fletcher for his guidance, encouragement, and assistance to the author while he was at Texas A&M.

My wife, Paddy, and our children deserve special recognition for their patience, understanding, and support during this period.

Mike Root

College Station, Texas
April, 1984

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INTRODUCTION

This report documents the prior professional work experience of PAUL M. ROOT which is being submitted, along with twelve additional hours of coursework, in lieu of the internship requirement for the Doctor of Engineering degree.

Waiver Of Internship

There are two primary objectives of the internship:

1. To enable the student to demonstrate and enhance his or her abilities to apply both knowledge and technical training by making an identifiable contribution in an area of practical concern to the organization or industry in which the internship is served.

2. To enable the student to function in a non-academic environment in a position in which he or she will become aware of the employer's approach to problems, in addition to those approaches of traditional engineering design or analysis.(1)

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1. "Doctor of Engineering Program Manual", College of Engineering, Texas A&M University, undated, p.5.

At the time of the author's entry into the Doctor of Engineering program, it was possible for the internship to be waived if the candidate had extensive experience of a suitable nature prior to entering the program.

In addition to other assignments of an engineering nature during his Army career, the author had spent three and one half years in the Automotive Branch of the Systems Engineering Division, Office of the Program Manager, XM1 Tank Systems (now M1 Tank Systems). During that period he was responsible for managing and monitoring the development of the AGT 1500 turbine engine for the XM1 tank. This experience has been allowed to be used in lieu of a separate internship.

Qualifications

When he served in the Program Manager's office, the author was a Major in the United States Army. He is now a Lieutenant Colonel and has over seventeen years of active military service. During this time he has attended various schools and held a wide variety of assignments.

His academic achievements include:

- Master of Science, Mechanical Engineering, Stanford University, 1969

- Graduate, Royal Armour Corps Long Armour Infantry Course, England, 1972

- Graduate, US Army Command and General Staff College, 1976

- Graduate, Defense Systems Management College, 1976

Significant assignments include:

- Research and Development Coordinator, US Army Test and Evaluation Command, Aberdeen Proving Ground, Md., 1970-71

- Instructor, Course Director, and Assistant Professor, Department of Engineering, United States Military Academy, West Point, NY, 1973-1976

- Research and Development Coordinator, Office of the Program Manager, XM1 Tank Systems, Warren, Mi., 1976-1980

- Tank Modernization Officer, Joint United States Military Mission for Aid to Turkey, Ankara, Turkey, 1980-1982

The author has been a Registered Professional

Engineer in the State of Virginia since 1976.

Organization Of Report

The remainder of this report is organized into several chapters and appendices. Chapter 2 describes the Office of the Program Manager, XM1 Tank Systems, its purpose, organization, and the author's position. Chapters 3 through 10 detail some of the major projects with which the author was involved, and the final chapter summarizes some observations made by the author during his assignment.

Chapter 2

OFFICE OF THE PROGRAM MANAGER, XM1 TANK SYSTEMS

General

The Secretary of the Army has the authority to appoint a Program Manager for Research, Development and Acquisition programs which will have a major impact on the Army. The Program Manager is delegated the full line authority of the Commanding General, US Army Materiel Development and Readiness Command for the centralized management of his assigned program. He is totally responsible for the success or failure of his program, and is the single point of contact for all decisions regarding his program. A Program Manager is an Army officer in the rank of Colonel, Brigadier General, or Major General, depending on the size, importance, cost, and visibility of the program. He is a commissioned officer, rather than a Civil Servant, so that he can be expeditiously replaced if the occasion should arise, a procedure not possible with members of the Civil Service.

The Program Manager usually has extensive field experience and a background in logistics, research and development, or program management. His most important attribute is that of a good manager, followed closely by his ability as a spokesman and salesman for his program to a wide variety of audiences, most notably Congress, which must annually authorize funding for the program.

To assist him in his task, he commands a Program Manager's Office, formed especially for his program and staffed with military and civilian personnel who have expertise in the areas required for effective management of the program. Depending on the program, his staff might include specialists in contracting, budgeting, logistics, systems engineering, production, procurement, product assurance, cost management, and other fields as required. Field Offices and Liaison Offices may be established at various military installations and test sites as required.

The organization of a Program Manager's Office is not static, but changes during the life of the program as it progresses through various phases. For instance, a logistics division may be minimally staffed during the early development stages of a program, but may become the prime reason for the continuation of a Program Manager's Office once the equipment is produced and fielded.

Program Manager's Office, XM1 Tank Systems

A Program Manager was appointed for the XM1 Tank Systems in 1973 after the termination of the joint United States-Federal Republic of Germany MBT 70 tank program. In authorizing the Army to begin development of a new tank, Congress, which was concerned with the failure of the previous program and the long development period for new military hardware, mandated that the first production should begin in 1980, thus allowing only seven years for design, development and testing of the new tank. While this may seem like a sufficient time, it was three years shorter than prudent estimates of the required development time, and would result in many problems.

The Program Manager's Office is located in Warren, Michigan, near the US Army Tank Automotive Command, from which most of its civilian personnel were drawn. It was initially staffed with approximately twenty officers and forty civilians and had grown by 1980 to approximately 45 military personnel and one hundred civilians. In 1980 liaison offices existed in Washington, DC, and Bonn, Germany, and field offices existed at Aberdeen Proving Ground, Md., Fort Knox, Ky., and Fort Hood, Tx. A subordinate Program Manager for Tank Main Armament Systems was located at Picatinny Arsenal, Dover, NJ.

Program History

The XM1 tank program was divided into three phases: Engineering Design, Full Scale Engineering Development (FSED), and Production. The Engineering Design phase was competitive and lasted three years. General Motors and Chrysler Defense Division both received contracts to develop one prototype tank and one automotive test vehicle. These were tested against the requirements specified in the Materiel Need document, an Army document which stated the performance requirements which the tank must meet. Many of these requirements were stated as minimum threshholds which the contractor had to meet, but could exceed, and by so doing receive additional credit in that area of performance evaluation. This allowed the contractor to make tradeoffs and optimize his vehicle design within the broadly stated performance parameters. It was hoped that this competitive procedure would result in the best possible tank.

The prototype tanks and automotive test vehicles were tested at Aberdeen Proving Ground by the US Army

Test and Evaluation Command in 1975 and early 1976. The results were used in the selection of the contractor for the next phase of the development program.

The selection of the contractor for the Full Scale Engineering Development phase of the program was of great importance, since that contractor would also receive the production contract for the tank, the ultimate payoff of the program. For this reason, absolute fairness and impartiality was required in the Source Selection Process. A three-tiered procedure was used. In addition to the performance of the prototypes, each contractor's proposal for the next phase would be evaluated in the areas of cost, performance and schedule. Each factor to be evaluated was enumerated, and a numerical scale was established for each factor to compare the performance of the two contractor's vehicles.

A Source Selection Evaluation Board (SSEB) was established to evaluate each factor considered in the decision. Its deliberations took a considerable period of time, and its findings were strictly limited to the scoring of each factor. It did not make a recommendation as to which contractor should be awarded the contract.

The Source Selection Advisory Council (SSAC), consisting of senior personnel in Washington, DC, received the report of the SSEB, and applied relative weights, which it independently determined, to each factor under consideration. The product of the score for each decision factor and its relative weight was then summed for each contractor. The SSAC then recommended that the contractor with the higher overall score receive the contract.

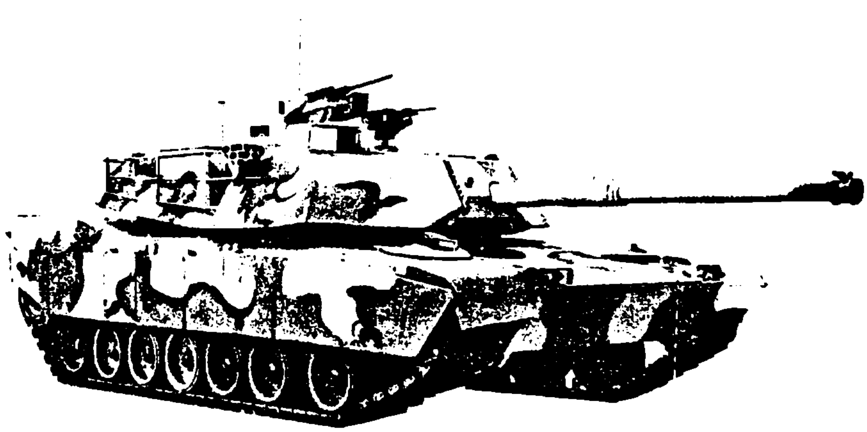
The SSAC made its recommendation to the Source Selection Authority (SSA), the Deputy Secretary of Defense for Research and Engineering. The SSA is not bound by the recommendations of the SSAC, but usually follows them.

The actual reports of the SSEB and SSAC are not available since they are highly sensitive, but the ultimate result was that Chrysler Defense Division received the contract for Full Scale Engineering Development in November 1976. The contract was a "Cost Plus Incentive Fee and Award Fee" type and the value was approximately $243 million. The incentives were based on actual costs being less than budgeted costs and were enumerated in the contract, but the award fee was solely at the discretion of the Program Manager, up to a maximum amount. He could withhold or award any or all of it based upon his evaluation of the contractor's performance, or he could defer a part of it to a later period, and the contractor had no recourse. The award fee was the Program Manager's leverage with the contractor to insure the technical quality of the tank as opposed to the cost, which was covered by the incentive fee. The major motivation to the contractor, however, was the fact that if the development program was not successful, the tank would not go to production, and the production contract was the prize. The recent failure of the MBT 70 tank program underscored that possibility.

The objectives of FSED were to prove the contractor's design, determine the tank's suitability for use by the Army, and insure readiness for production . These objectives were to be met by production of eleven prototype tanks and an extensive vehicle and component test program. A photo of the XM1 is at Figure 1.

The vehicle testing included contractor's testing, Development (engineering) testing at various government test sites, and Operational testing, involving a platoon of five tanks tested under field conditions by soldiers at Ft. Bliss, TX. The performance in the Development and Operational testing was evaluated against requirements as stated in the Materiel Need Document, and all failures and problems were scored using an elaborate system which

XM1 Tank (3/4 Left Front View)



XM1 Tank (3/4 Right Front View)

Figure 1. XM1 Tank

assessed Mission Reliability and Combat Mission reliability, and compared those reliabilities, stated as Mean Miles Between Failures (MMBF), against the stated requirements. Normally, contractor testing would precede Development and Operational testing so that the contractor could correct design problems discovered prior to government testing. The compressed development schedule did not allow for this, however, and Development and Operational testing were well underway prior to the start of any contractor testing. Many problems which should have been discovered and corrected during contractor testing were not uncovered until Development and Operational testing, and these problems caused the tank to receive much bad publicity.

Component testing, on the other hand, was generally conducted to insure a component's design maturity prior to testing in the tank. A notable exception was the engine, which had separate durability requirements which had to be met in component testing.

The FSED phase lasted until early 1980 when the first production tank was accepted by the Army. When the tank entered production, the "X" was dropped from its designation, and it became the M1 Abrams Tank, named after General Creighton Abrams, an Armor officer and former Chief of Staff of the Army. Production initially began at a low rate at the Lima Army Tank Plant, Lima, Ohio, and has grown to sixty per month with the addition of the Detroit Army Tank Plant. As of 1980, production was scheduled to continue through 1989 with a total production of over 7,000 tanks.

AVCO Lycoming AGT 1500 Turbine Engine

As long as the tank met the performance requirements of the Materiel Need document, each contractor was free to choose those components he desired, including the type of engine. General Motors had chosen a 1500 HP variable compression ratio diesel engine for its tank, and Chrysler had chosen the AVCO Lycoming 1500 HP recuperated gas turbine engine for its version.

The turbine engine had been under development by the Tank Automotive Command since 1965, and Chrysler chose it for its tank due to its light weight, size, and performance. The engine was not fully developed prior to being included in Chrysler's tank, and the result was that the tank and the engine were being developed concurrently, which resulted in many problems. A drawing of the engine is at Figure 2.

The engine had been developed specifically for

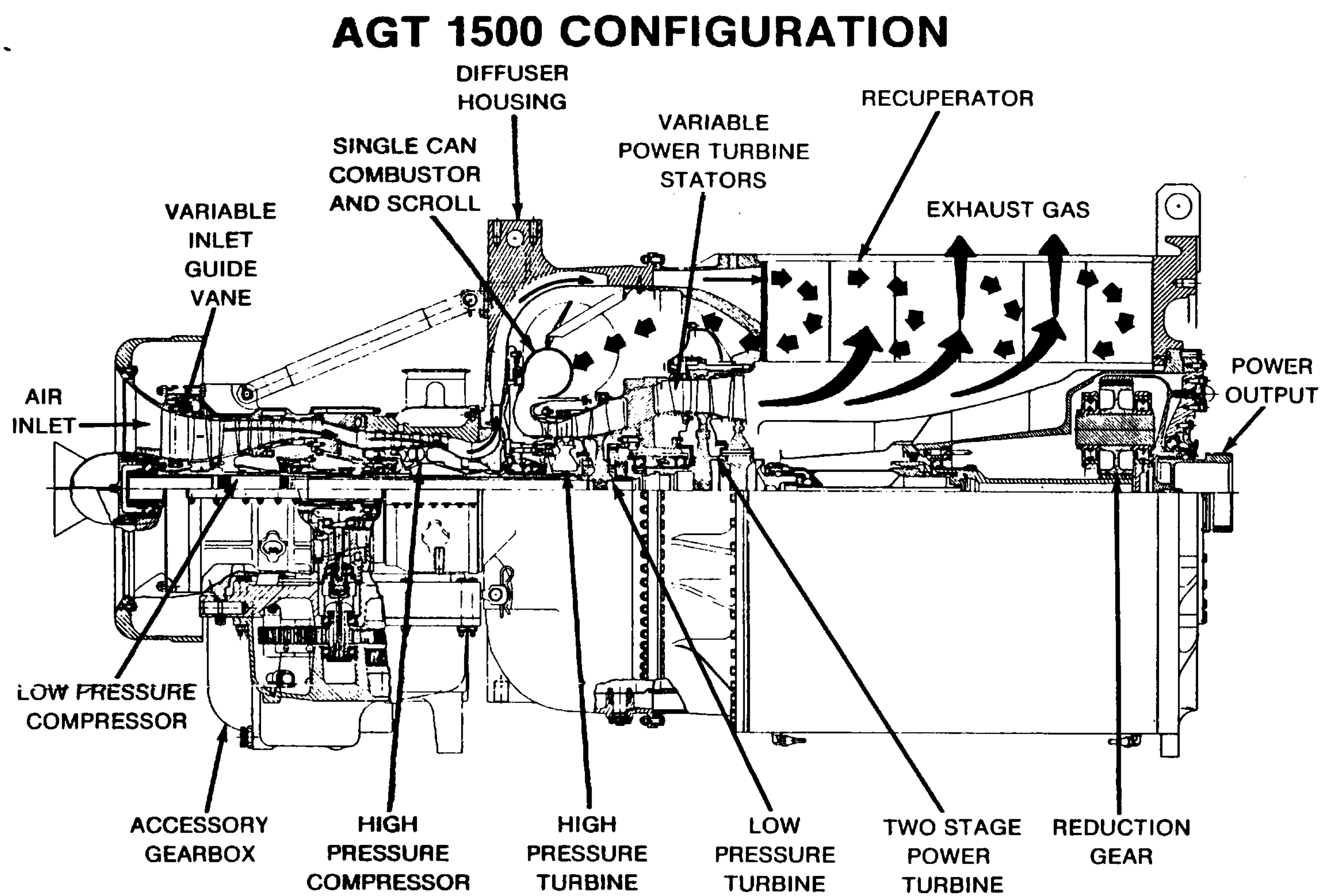


Figure 2. AGT 1500 Turbine Engine

ground vehicle usage, and weight was not as important as in aircraft applications. The engine housings were constructed of inexpensive steels and cast irons rather than lightweight alloys, and this contributed to the engine's ruggedness and weight of 2500 lb., compared to 400 lb. for an aircraft turbine of similar power. Another factor contributing to the engine's weight was the recuperator, or heat exchanger, which preheated the incoming compressed air to the combustor and greatly reduced the fuel consumption at part power.

To be compatible with the Army's logistics system, the engine was multifuel: its normal fuel was diesel grade DF2, but it could burn any vehicular grade of diesel fuel, jet fuel, or gasoline with no adjustments and no damage to the engine. The fuel flow rate to the combustor was controlled by the turbine inlet temperature, and no matter what fuel was being used, the fuel control would prevent the maximum allowable turbine inlet temperature from being exceeded.

The engine was built in three major modules: the forward, rear, and accessory gearbox modules (Figure 3). These could be replaced by maintenance personnel in the field with few special tools and no critical alignments; the modules just bolted together. Most engine

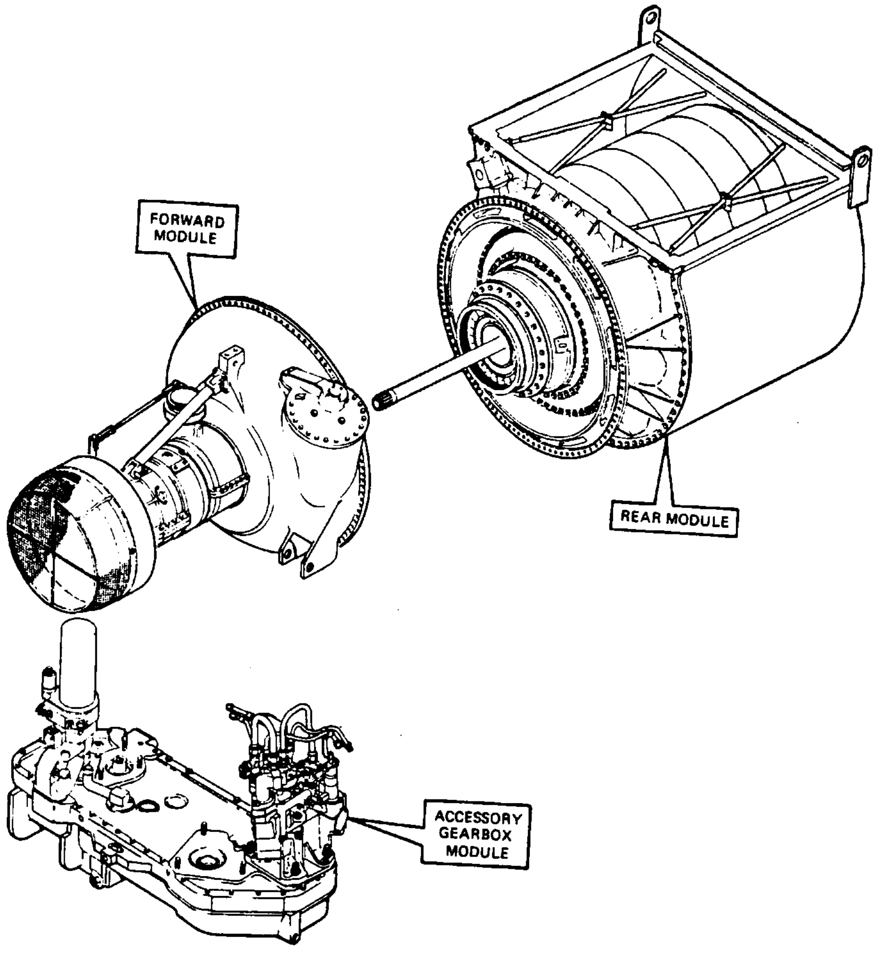


Figure 3. AGT 1500 Modular Construction

accessories including the starter, fuel nozzle and oil filter could be replaced without removing the engine from the tank, thus greatly facilitating maintenance.

The turbine required no external cooling system, either air or water, as a diesel engine would, but the airflow through the engine was much greater than would have been the case for a comparable diesel engine, and this was potentially a source of problems. At maximum power the engine required 10,000 CFM of filtered air, and consequently the air filters had to be large. There had been no problem with them during the competitive phase of development, but poor air filtration was to cause many problems during FSED.

The Author's Assignment

The author was assigned to the Automotive Branch of the Systems Engineering Division in December, 1976, and remained there until July, 1980, when he was reassigned to Ankara, Turkey. His assignment coincided with the FSED phase of the development of the tank.

The Systems Engineering Division of the Program Manager's Office was responsible for management of the technical development of the XM1 tank. It contained a

Firepower Branch, responsible for the armament and fire control systems, an Armor Branch, responsible for the development of the secret "Special Armor" which gave the tank protection far superior to that of any other tank in the world, a Product Assurance and Test Branch, responsible for quality control and monitoring the conduct of the Development and Operational tests, a Systems Integration Branch, responsible for insuring the effectiveness of the total system, and the Automotive Branch, which was responsible for the automotive systems in the tank, including the engine, transmission, electrical, fuel, track, suspension and auxiliary automotive systems.

The Automotive Branch was staffed by three Civil Service engineers, a secretary, and the author. The Branch Chief was initially Mr. Irv Smith. During the author's assignment Mr. Smith took a position with civilian industry, and the author became acting Branch Chief for several months. Mr. Lou Gerback was assigned as Branch Chief and remains in that position. Mr. Will Harju was responsible for the hull electrical and auxiliary automotive systems, including the track and suspension, and Mr. Bill Appleyard was responsible for the transmission. The author was responsible for the engine and related systems. For most of his assignment, the author was the only officer in the Program Manager's Office serving in a technical engineering position.

During the author's assignment the engine progressed from advanced engineering development to a mature design, ready for production, due to extensive engineering effort on the part of AVCO Lycoming and an extensive test program consisting of both laboratory engine tests and vehicle tests for performance, reliability, and durability. The value of the contracts for engine development during FSED was approximately $50 million.

The author's responsibilities included:

1. Managing the $50 million engine development program for the XM1 tank.

2. Acting as military advisor to the Chief, Automotive Branch, with respect to vehicle mobility, agility, and vulnerability.

3. Developing, designing, managing, and evaluating laboratory and vehicle test programs for the engine and related automotive systems.

4. Evaluating engine and powerpack performance, reliability and durability.

5. Preparing and presenting technical briefings on the

engine, including acting as principal briefer to other US government agencies and foreign governments.

6. Representing the Program Manager with other agencies on related engine and automotive programs.

The relationship between the author, as the representative of the Program Manager, and AVCO Lycoming, the contractor for the engine, was unique. Chrysler Defense Division was the prime contractor for the tank, and AVCO Lycoming was the subcontractor for the engine. Chrysler had "total system responsibility" for the tank, which gave it nearly total engineering freedom, so long as the tank met the stated requirements. Any directions given to the contractor had to be formalized with contract modifications and usually involved additional costs. Only the designated contracting officer in the Program Manager's Office could legally direct the contractor to change the scope of work of the contract, so the author could not directly order either Chrysler or AVCO to do anything. His success depended on his credibility, rapport, and ability to convince the contractor that what needed to be done would benefit the program. Fortunately, most of the people encountered were dedicated to the program's success and to fielding the best engine possible in the tank, and cooperation was the order of the day. When problems arose, people attempted to solve them in a manner which would result in the best possible tank.

Although the author's formal assignment was responsibility for the engine and related systems, his actual job encompassed much more than the technical aspects of those systems. The Program Manager's Office was created to develop and field the tank, and most personnel were "mission oriented", that is, they did whatever jobs were necessary or assigned to accomplish the job at hand, without regard to job title. One of the factors which made the author's assignment to the Program Manager's Office so enjoyable was the wide variety of projects in which he became involved. The following chapters describe some of the major areas in which the author became involved and his responsibilities in those areas.

Chapter 3

THE AGT 1500 TURBINE ENGINE

The author's principal responsibility was to become the Program Manager's representative for the engine, not only for the technical aspects, but the operational aspects as well. One of his early tasks was to write a "Fact Sheet" about the engine, its technical operation and functioning, and the status and cost of the engine development program. This was used by the Program Manager as a refresher before he testified at Congressional Budget Hearings on the tank (Appendix A-1), and by others to familiarize themselves with the engine.

During this testimony, it was commonplace that many technical questions were not answered during the Hearings themselves, but that the answers would be provided for the Congressional Record. An example of these questions, and the answers written by the author, is given in Appendix A-2.

A significant amount of time was spent at the contractor's plant observing engine assembly, disassembly, testing, and participating in engine teardowns and failure analysis. The author investigated engine failures which resulted from laboratory and vehicle testing and wrote the reports on those failures, including analysis of the contractor's proposed corrective actions. These were used to inform the Program Manager of the nature of the failures and the adequacy of the contractor's proposed actions. Examples of these reports are at Appendices A-3 and A-4. The author's report on an incorrect bearing assembly in the engine, which led to several engine failures and a redesign of the component is at Appendix A-5.

One of the more interesting failures occurred when the first stage Low Pressure turbine failed during operation. The Low Pressure turbine was an integrally cast wheel and disc. It was initially cast from a high nickel alloy material, C101, but it was changed to C103, a slightly different material which had somewhat better stress rupture properties. It appeared to be a minor change. This material had been extensively used for turbine blades in the past but had not been used in integrally cast disc and blade assemblies. Investigation of the failure showed that a fatigue fracture had started at the trailing edge of one of the blades. The manufacturer's report concluded that the wheel had failed from a combination of low and high cycle fatigue. Miner's Rule was being used by the manufacturer to predict fatigue life under the combined high and low cycle fatigue loading which was encountered during normal operation. This criteria states that fatigue failure will occur when the sum of the life fractions of fatigue at each stress level add up to one. The manufacturer stated that the failure occurred at a life of .33 as predicted by Miner's Rule, and that there were "synergistic effects of transients not previously observed in industry," which were responsible for the failure. This conclusion was accepted by the prime contractor, the author, and several outside experts in turbine engine design, who had been brought in as consultants for solution of the problem.

The problem was eventually solved by redesign of the wheel. The final design used a forged disc and individually inserted cast blades, and the problem did not recur. However, while at Texas A&M, the author had the opportunity to investigate the problem further. He discovered that the engine manufacturer's conclusion that the failure was due to previously unobserved effects was incorrect. His investigation showed that Miner's Rule was, at best, a poor approximation for life under combined fatigue loading, and that experimental results gave failures at Miner's Rule values of .3 to 1.5. Additionally, agreement to a factor of 2 is considered good for pure low cycle fatigue experiments, so a wide scatter band should have been expected, and, in fact, the failure occurred at what should have been considered the low end of the band. This "turbine fatigue" problem has since been observed in other turbine engines run to continuously varying duty cycles. The engine for the F-16 fighter aircraft encountered this problem.

Twenty new engines had been built for the FSED phase of the program, and by the end of the phase there had been forty engine failures which occurred in vehicles undergoing test, and sixteen engines had been removed for major repair prior to failure. The choice of the turbine engine had been somewhat controversial and news of the failures traveled quickly. One of the author's continuing tasks was to compile and periodically update a "FACT SHEET" categorizing all the failures and listing the corrective action taken to prevent similar failures in the future. These reports were important because the engine had a durability requirement of a "50% probability of going 4,000 miles without a durability failure", and it was obvious merely from the number of failures that the engine would not meet that requirement. Therefore accurate knowledge of the number of failures, their cause, and corrective action was of great interest to many people, both inside and outside the Program Office. Appendix A-6 is the updated Fact Sheet written by the author near the end of the FSED phase.

The author also spent considerable time at the field test sites observing the operation of the engine and the tank during both Operational and Development tests and troubleshooting and reporting on problems (Appendices A-7 and A-8). These observations and discussions with soldiers who operated the tank provided valuable information concerning actual problems, practical solutions to those problems, and suggestions for realistic improvements to operating procedures.

As the Program Manager's representative for the engine, the author prepared and gave numerous briefings. Since this was the first turbine engine ever used in a military ground vehicle, few people were familiar with the operation of a turbine engine. Those who were had been exposed to helicopter engines, and the AGT 1500 bore little resemblance to an aviation turbine. The author briefed visitors to the Program Office, senior Army officers and civilians, Congressional Staff members, and members of foreign governments which had expressed an interest in the new tank. As testing progressed these briefings grew to include engine failure analysis and comparison with other engines, including diesels and helicopter turbines which outsiders felt might be suitable substitute engines for the tank in case the current engine development was not successful. Copies of the Vu-graphs from a representative briefing written and presented by the author are at Appendix A-9.

Chapter 4

RELATED SYSTEMS

The author's responsibilities extended to those systems related directly to the engine and included the air induction and filtration system, the electronic fuel control, the fuel pumps and filters, and the lubrication system. Of these, the air filtration system caused the most problems and received the greatest amount of publicity.

Air Cleaner

The air cleaner system consisted of a large rectangular box into which three "V"-shaped filters were inserted. Air entered a centrifugal precleaner at the top of the box, and then passed through the outside of the "V"-pacs and the filtered air left through the top of the "V". The "V"-pacs were held against openings at the end of the box by a lever and cam system, and there were rubber seals on the top of the filters to insure no unfiltered air bypassed the filters. The filtered air then passed through a plenum where it was directed into the engine inlet. A large flexible rubber seal connected the air plenum to the engine inlet. Appendix B-1 is a schematic of the system.

There had been no problem with the air filtration system during the engineering design phase, but as soon as the FSED tanks began testing at Ft. Bliss, TX, engine failures due to dust ingestion began, and they plagued the tank throughout its testing. Nine engine failures and two removals prior to failure were attributed to the air filtration system. Appendix B-2 is the author's report on one of the engines which failed due to dust ingestion.

The problem was traced to the production of the filter system. Chrysler had decided to manufacture the box itself, welding it from aluminum plate. They did not hold the tolerances close enough, and the end of the box with the openings for the filtered air was not perpendicular to the floor of the box. Consequently, the seals of the "V"-pacs did not contact the box all the way around the end of the filter, and unfiltered air entered the engine. Additionally, the seals themselves, which were cemented to the end of the "V"-pacs, were subject to damage and could be stripped from the filter on installation, also allowing unfiltered air to bypass the filters.

This problem was compounded by two other factors. First, the sand at Ft. Bliss is silica-based and extremely abrasive, and sand ingestion is a problem there for all types of engines, not just the turbine. When sand entered the turbine engine, it would abrade the compressor blades, changing their airfoil shape and eventually causing compressor surge. As it passed through the combustor, it would melt, and then resolidify on the turbine blades as it cooled.

Second, the first stage of the high pressure compressor had a very short surge life and would fail catastrophically, damaging subsequent compressor stages. This occurred with little or no prior warning.

The turbine engine received very bad publicity from these failures, although the major problem was with the air filters, and the engine manufacturer, AVCO Lycoming had no responsibility for them. A great deal of the author's time was spent with Chrysler and AVCO Lycoming evaluating these failures, determining corrective actions, and planning for their implementation and phasing into the ongoing test program. Appendix B-3 details one of the early meetings in which the author participated. Further time was spent in authoring Fact Sheets and giving briefings on these failures and the design changes which would eliminate the problem. An Information Paper on the subject, written by the author, is at Appendix B-4.

The problem was solved by several design changes. Production standards on the air cleaner boxes were tightened so the ends were square. The seals were recessed in grooves in the air cleaner box to protect them from damage, and the top of the "V"-pacs were modified to have a raised lip which engaged the recessed seals (see Appendix B-5). The lever and camming mechanism, which held the "V"-pacs in place was modified so that the air precleaner could not be installed unless the "V"-pacs were properly installed. Additionally, AVCO redesigned the first stage of the high pressure compressor so that it had a much greater surge life and thereby could tolerate more erosion prior to failure.

It took some time to implement all the design changes, and positive confirmation was required of their effectiveness. In late summer and early fall of 1979 a 1,300 mile test was designed and run in the dust bowl area of White Sands Missile Range, adjacent to Ft. Bliss. The tank used had all the air cleaner modifications on it. The author assisted in setting up the test courses (see Appendix B-6), and evaluated the conduct of the test (Appendix B-7). The engine was calibrated before and after the test, and no engine degradation was found. The modifications subsequently entered production. The major difficulty was convincing decision makers, who were generally non-engineers, that the problem was being solved, that the design changes appeared adequate, that there would be sufficient testing to confirm the changes, and that the engine could operate in a dusty, sandy, desert environment.

One problem left unsolved was the difficulty of cleaning the "V"-pacs. When clogged they contained 20-25 pounds of dust, and they were cleaned with compressed air, a job that could take over an hour per "V"-pac. In addition to being an extremely dirty job, it would take a tank company of seventeen tanks (51 "V"-pacs) many hours to clean all their filters completely since there are very few adequate sources of compressed air in a tank company. A method of partially cleaning the "V"-pacs in the field by gently dropping them on a flat surface was developed to allow expeditious cleaning and this proved satisfactory. When the author departed the program proposals for other methods of cleaning the filters were being evaluated, and the author is unaware of the current status of this problem.

New air filter concepts and designs were also being studied, and the author evaluated them. Most novel among these was one which cleaned itself periodically by automatically vacuuming its surface. It was an interesting concept, but the author felt its major drawbacks were its extreme mechanical complexity and small dust capacity should the self-cleaning feature break down.

Fuel Control

The engine had an analog electronic fuel control, unlike most turbine fuel controls which were hydromechanical, and it was a new design for FSED. It was designed to sense several parameters during engine start and operation and either shut down the engine or reduce its power if the parameters were not within the prescribed operating windows. The control monitored engine speed, turbine inlet temperature, battery voltage, oil pressure, and several other parameters. The author wrote several memoranda and Fact Sheets explaining the fuel control's operation to other members of the Program Office (Appendices B-8 and B-9). Additionally, it was found that the draft Operator's Manuals for the tank did not adequately explain the starting procedure, so the author addressed it in a Memorandum which was intended to be included in a revision to the manual (see Appendix B-10).

The fuel control had several design problems which were discovered during testing and had to be rapidly corrected. Ideally they would have been discovered during contractor testing, but due to the accelerated program schedule, they were first encountered in Operational or Development testing where they were treated as failures for scoring purposes. It was found that the operating windows for some of the control parameters were too restrictive and in some cases the engine would not be allowed to start. In other cases it was found that engine power would be reduced when it was not necessary because the control had sensed a problem which did not really exist. The author participated, as the representative of the Program Manager, in the decisions for the reprogramming of the fuel control. Fortunately, the fuel control manufacturer was able to correct these problems rapidly since they involved changing components on a printed circuit board and not the remachining of complex cams and levers as would have been the case if it had been a hydromechanical fuel control.

One of the persistent complaints about the engine was unexplained "vehicle loss of power". A driver would somehow sense that the tank had less power than it previously had, and would enter the report in the logbook. During vehicle testing, this would be scored as a failure, and in some instances the engine and fuel control were operating as they had been designed to. It became necessary for the author to write a memorandum explaining the function of the fuel control, its protective modes which resulted in "loss of power", and the procedures for resetting the fuel control for full power operation (Appendix B-11). This was sent to the test sites and, hopefully was included in later versions of the Operator's Manual.

Fuel Filters

The fuel filtration system also caused problems at first. The filters were initially sized too small for long life between servicing, and they were designed without an adequate bypass system when they became clogged. Consequently, the engine would become starved for fuel. The author participated in the redesign of the system and implementation of modified maintenance procedures to further reduce the effects of the problem.

The performance of the XM1 was continually compared with that of the present tank, the M60, and whenever the XM1 did not outperform the M60, it was cause for concern. The user did not want to get something worse than he already had. The fuel filters clogged more often than those of the M60, so the author had to attempt to explain the difference. Appendix B-12 is a Fact Sheet which defines the problem, but offers no solution.

Maintenance Monitor

The driver's station includes a maintenance monitor panel which contains warning and caution lights for various engine and other systems. These include filter clogged lights, oil pressure and temperature warning lights, and engine overtemperature and overspeed lights. When certain lights came on, the fuel control automatically took protective action, but in all cases the driver had corrective action he was required to take, either immediately or at the next break in operation. One of the author's tasks was to correct the Operators' Manual so that the instructions were proper.

The author rewrote the instructions for the Operator's Manual to conform with what was actually necessary. His input (Appendix B-13) included identification of each warning and caution light, what the light indicated, and the required crew action to correct the malfunction. For instance, the oil filtration system was designed so that the filter clogged light would come on when a certain pressure drop existed across the filter. The system was designed for "on-condition" maintenance, that is the filter should be changed at a reasonable time after the filter clogged light came on. Initially, the manual instructed the driver to stop immediately and change the filter, an impractical and unnecessary procedure. As a result of the author's efforts, the manual was subsequently changed to reflect the fact that the current mission could be completed prior to servicing the filters, as was the original intention.

Chapter 5

FUEL ECONOMY

Fuel consumption was of interest for several reasons, and the author spent a great deal of time calculating, evaluating, and justifying various fuel consumption figures to many outside parties and agencies.

The supplying of fuel to units in the field under combat conditions is one of the most difficult requirements placed on the logistics system. Military history holds many examples of operations which had to be halted or delayed because of lack of fuel at the front lines. The turbine engine for the XM1 was rated at 1500 HP, compared to the diesel in the current M60 tank, which was rated at 750 HP. An increase in fuel consumption was to be expected for the new tank, and determination of its magnitude was important because additional fuel trucks would have to be added to supply units to accommodate the needs of the new tanks.

There was a great deal of interest in how far the tank could run without refueling on secondary roads so that a cruising range for road marches could be determined. Current doctrine calls for tanks to be refueled daily in battle, and an estimate of the fuel consumption for a typical operational "battlefield day" was also required. Consequently, the Materiel Need document specified two different fuel consumption requirements for the tank. The first was that the tank should have a cruising range with onboard fuel of 275-325 miles on secondary roads (dry, hard dirt roads) at 25 mph, and the second was that the tank be able to complete a hypothetical "battlefield day" mission profile with onboard fuel. This mission profile was based on a worst case (greatest mileage) situation and consisted of specified distances on secondary roads and cross country at given speeds and a number of hours of engine idle. The fuel consumption for each of these requirements was calculated from data available from the Development tests, and, to further confuse matters, various outside agencies used different mission profiles for their analyses.

Several different fuel consumption tests were run, both under controlled and relatively uncontrolled conditions. All of these data were widely available and were often used by these outside groups without verification of its accuracy. Data from the discrete fuel consumption tests were reasonably repeatable. However, different vehicles at different times gave different results, and the non-engineer decision makers were uncomfortable with a range of values for the fuel consumption. They wanted a single, repeatable number for secondary road fuel consumption that they could use in computing the cruising range and a single value for battlefield day fuel consumption. In addition to the variation between vehicles, the problem was complicated by the fact that there is no "standard" secondary road. A secondary road is a dirt, clay, or gravel road, and the rolling resistance varies between the different types of surfaces, as well as for the same surface for various climatic conditions. These conditions made complete repeatability nearly impossible.

Fuel consumption data were taken from the operations at Ft. Bliss and used without the knowledge of the Program Manager. These data were very unfavorable to the XM1, and it was not until the author investigated that it was found that they were gross data, taken over an interval of about a month, during a period when the tanks were not operating to any typical mission profile. It was also found that some of the fuel tankers used did not have functioning fuel metering devices, and what was supposedly data was, in fact, just someone's estimate. The topic became so confusing that it was necessary for the author to write an Information Paper concerning fuel consumption in an attempt to explain the different figures and rationalize the differences between them (see Appendix C-1).

The Commander of the Armor Center at Ft. Knox, KY, received some of the uncontrolled fuel consumption data and remarked about how bad it appeared. The author was then tasked to write a "White Paper" (Appendix C-2) on fuel consumption and the various figures that existed. At the same time, it had become necessary to increase the track tension on the tank, and this increased its rolling resistance and thus its fuel consumption by about 10%, which further complicated the fuel consumption data.

As a further complexity, the manufacturer of the diesel engine which had not been chosen for the XM1 continually claimed that his engine had superior fuel economy when compared to the turbine. At the same time, there were people who favored the diesel engine, and it became necessary for the author to write an Information Paper comparing the fuel consumption of the turbine with that of the diesel. Since the diesel had not been chosen, the only data available for its fuel consumption came from the previous phase of the program. Any comparisons, therefore, were hypothetical since no new diesels had been produced, no side-by-side testing occurred, and the tank had increased in weight since the previous phase. Appendix C-3 is the author's attempt to compare these two engines.

Each Spring the funding for the tank program was subject to review during the Congressional Budget Hearings, and one of the author's tasks was to prepare answers to possible questions which the Program Manager or the Chief of Staff of the Army might be asked during those hearings. Appendix C-4 is an example of the questions and answers prepared by the author on the subject of fuel consumption.

In early 1980, the difficulty in achieving repeatability in the secondary road fuel consumption tests became important to the contractor, since a portion of his fee depended on meeting the cruising range requirement. By letter, he proposed that a 300 mile range on paved road be used instead of a 275 mile range on secondary road. The use of paved road would help repeatability. The author evaluated this proposal (Appendix C-5) and determined that, based on fuel consumption rates, the two were not equivalent. Instead, after considering the best available, he proposed a 340 mile range as being equivalent. He departed the program for his next assignment before the question was finally resolved.

It had become evident to the author and to many people that a wide range of numbers did exist for fuel consumption, and that each of those numbers was valid for the particular circumstances under which the data was taken. It was also evident that many people were uncomfortable with a range of values for fuel consumption-it was difficult to make a decision based on a range of values. Before the author departed the program, he summarized the entire problem on one sheet of paper (Appendix C-6), and he hoped that this would finally resolve the question.

Chapter 6

ENGINE AND VEHICLE TESTING

It was imperative that the engine be successful, or the entire tank program could be put in jeopardy. Since the engine was still under development at the beginning of FSED, extensive laboratory testing was scheduled for this phase of the program. The engine development program was funded at over fifty million dollars, and over 7900 hours of laboratory testing were scheduled for the engine, as well as nearly 100,000 miles of vehicle testing during which the engine would be evaluated. Further testing was added during the FSED phase to provide verification of fixes to problems discovered during the testing, and the author assisted in the design of some of the test cycles and in establishing their equivalence to field usage.

Development of a realistic mission profile for engine usage which could be reproduced in the laboratory on a dynamometer test stand was challenging, since there is no "typical" mission profile for usage of a tank engine as there is for an aircraft engine. The 400 Hour Durability Test Cycle (Appendix D-1) was based on a NATO standard test cycle, and was used as a baseline for comparison of durability with other production engines. The Low Cycle Fatigue (LCF) test cycle (Appendix D-2) was excellent to stress hot-end turbine components, but was not representative of any operating conditions. The Mission Profile test (Appendix D-3) was derived from a powerpack mission profile test which was in turn developed from an instrumented vehicle test. In this test, the throttle position was set and the load on the engine was varied to obtain the required power turbine (PT) speeds. This test had a large number of transients which had been found to be a critical parameter since thermal and low cycle fatigue damage could occur during them and many failures occurred during the transients.

There were more than enough engine failures, but one was caused by the test cell configuration, and the author was required to attempt to convince interested parties that the failure could not possibly have happened except with that particular test cell equipment. A high-speed fuel shutoff valve inadvertently shut the engine down from high power, and the test cell engineer apparently attempted to reset the valve before the engine stopped. Fuel was blown through the still-rotating engine without igniting until it contacted the hot recuperator where it ignited, burning the recuperator. Since it was impossible to duplicate this failure mode in the vehicle, the author classified it as a test cell incident so the failure would not be charged against the engine (Appendix D-4). This failure was particularly annoying since the non-engineer decision-makers had difficulty understanding what actually happened and why the failure should not be charged against the engine.

One of the requirements for Army equipment is the ability to start and operate at temperatures down to -65 degrees F. One of the turbine engine's stated advantages was its easy cold starting capability compared to a diesel engine, and engine and vehicle cold starting tests were part of the FSED phase. This type of testing is very time-consuming since the engine must cool to the ambient temperature between starts. Usually, only one start per day can be made.

Engine cold start tests were conducted by the manufacturer with varying degrees of success. Vehicle tests were more difficult. The Army's cold start test cell is quite old and not large enough to provide the volume of cold air needed by the turbine engine. Additionally, the cell is too small to test the functioning of the turret traverse and stabilization system. The Air Force has an extremely large cold room at Eglin AFB, Fla., where they test aircraft, and arrangements were made to test the tank there.

Many problems were encountered with the originally scheduled test in late July 1979 including the lack of a production-type fuel nozzle for the engine, the unavailability of suitable arctic fuel in time for the test, and the lack of a good test plan. The author wrote a small Staff Study (Appendix D-5) stating the problems, outlining the facts, exploring the alternative courses of action, and finally recommending a four-month delay. The recommendation was accepted and the test was delayed.

One of the author's challenges was to keep the engine testing realistic. Various outside consultants and review groups had their own ideas of what tests the engine should pass before it should be allowed to go into production, and many of these were very severe overtests of the engine. While the tests would provide interesting data, the author felt they were not essential at that point in the development program, and if failures occurred, they would be viewed as further proof that the engine was not ready for production instead of as indications where product improvements could be made.

A turbine engine expert from the Navy, who had accompanied an Admiral on a visit to the engine manufacturer and had sometimes been a consultant to the program, proposed "penalty runs" on any components which failed a 1000 hour test of the engine. This test consisted of a 400 hour NATO durability test followed by a 600 hour mission profile test and was an overtest of the engine, representing 17,000 to 20,000 miles of operation. The "penalty run" would consist of taking the replacement parts for any components which failed, and, after the completion of the basic 1000 hour test, running them in another engine to the specified test cycle until they reached 1000 hours of operation.

In addition to the lack of engine assets, time, and funds to conduct such tests, the author's investigation (Appendix D-6) revealed that this requirement was not placed on any other engine, even aviation engines, as a condition for production acceptance of that engine. The only similar requirement which could be found was that if an Army aviation engine component failed during its 150 hour qualification test, that component would be subjected to a specialized abbreviated test designed to stress that particular component. The Navy consultant's idea of "penalty runs" was apparently his own and was not used by any service, yet the proposal was taken seriously until it was discovered that it was not the widely accepted practice he would have had people believe.

As additional testing was added during the program, the contractor rightfully requested additional funding. The author often was required to provide independent estimates of the cost of additional testing or to validate costs submitted by the contractor. Usually these estimates were needed immediately, so detailed costing was impossible, but these "quick and dirty" estimates often were given great credibility and were difficult to revise. It was not unusual for the author to see one of his cost estimates appear as a line in next year's budget, and then it was impossible to change. Consequently, the tendency was to insure that the funding would be sufficient, and these estimates tended to be high.

Chapter 7

LOGISTICS

One of the most important considerations in fielding a new weapons system is the provision of adequate logistics support for that system. Logistics includes training of crew members and mechanics, establishment and verification of maintenance procedures, provision of operating and maintenance manuals, and provision for and supply of spare and repair parts. If the logistics support required for a weapons system has not been adequately considered, the system soon becomes ineffective and useless. "For want of a nail..."

The Program Manager's Office had a Logistics Division and the author assisted members of this division in several specific areas related to the engine. His efforts in correcting portions of the Operator's Manuals have previously been described.

Test Sets

AVCO had provided two test sets for the engine for FSED, and part of the test program was to evaluate the test sets. The Organizational Test Set allowed the tank unit mechanics to diagnose minor problems with the engine and its accessories, and it worked fairly well. It was computer-based and conducted electronic tests of proper circuit functioning, cable continuity, and proper operation of certain accessories. It did occasionally fail, and one of the author's concerns was that the contractor develop simple and adequate backup methods for troubleshooting the engine. There were only one or two Organizational Test Sets per company of tanks, and if they were in use or inoperative, it was still necessary for the mechanics to be able to perform their jobs. The initial backup troubleshooting procedures were very cumbersome and the author attempted, without much success, to get them simplified so that they would be useful to a mechanic.

The other test set was to be used by Direct Support (DS) maintenance units. Engine modules were to be replaced at this level of maintenance, and the engine was designed for easy substitution of modules. The Direct Support Engine Test Set was designed to be used when the engine suffered a substantial loss of power but could still operate. Vibration and speed sensors were attached to the engine, and the engine was run. The data collected would supposedly enable the mechanic to determine which module needed to be replaced.

In theory it was a good system, but in practice, it was never used. Of all the engine failures which occurred during FSED, there was never a failure in which a substantial loss of power occurred and the engine could continue to be run. The author helped to convince the contractor that a different test set was required for Direct Support Maintenance.

Ground Hop Console

The engine and transmission are removed as a unit from a tank, and they are often tested, after repair, by connecting to the tank's controls by extension power, fuel, and control cables. The power pack is then "ground hopped" while it is sitting on the ground, and adjustments are easy to make since there is good access to the power pack. Most maintenance units have fabricated "ground hop consoles" for the powerpacks of their current tanks. These consist of batteries for starting, a fuel tank, necessary instrumentation, and connectors so that the extension cables can be hooked to the engine. The mechanics can then test power packs without the necessity for a tank being present.

Since engines are repaired at Direct Support maintenance units, the author felt it was necessary that they be able to be tested prior to being reissued to the using units. The contractor initially stated that since the engine was modular, there was no need to test it once it was reassembled. The maintenance unit has no tanks of its own, and the author felt that it was necessary that a "ground hop console" be developed for the turbine power pack which would enable the engine and transmission to be tested after they had been repaired. He also felt that this console would be very useful to the Organizational mechanics in the tank units in the performance of their maintenance. The need for an electronic fuel control, which was not mounted on the engine, and would have to be a part of the console, made it impossible for the units to build their own.

The author had seen a console which had been manufactured by Chrysler for its own use, and requested that Chrysler provide a cost estimate on a production version which could be used by troops. Instead of merely a ruggedized version of what had already been developed, the contractor produced a plan for an extremely expensive, highly sophisticated console which actually did little more than the prototype. This was not what was needed, but the author departed the program before this subject was resolved.

Depot Spare Parts

June 1980 to June 1981 was scheduled to be Low Rate Initial Production (LRIP) for the tank. During this period, the initial production models of the tanks would undergo Development Testing to insure that the production models met the requirements for the tank and that changes identified in FSED had been successfully incorporated. In addition, Operational testing of a full Tank Battalion of 54 tanks was scheduled at Fort Hood, TX, to determine the tactical operational effectiveness of the tank when in simulated combat and to insure that soldiers could easily operate and maintain the tank. Additional engine testing was also planned. This phase was covered by a one year contract with Chrysler, and after that full scale production would begin. Detailed planning for this phase began in 1979.

Based on FSED experience, it was obvious that there would be engine failures and that AVCO would be required to rebuild and overhaul those engines, since there were very few spare engines in the LRIP contract. The author obtained a copy of the Depot Spare Parts List for which Chrysler had contracted. The parts list had been generated by the logistics section at Chrysler and approved by the Logistics Division of the PMO without review by Chrysler engineers or by the Automotive Branch of the PMO.

The author reviewed the list and found that there were many critical parts missing from it, such as turbine and compressor blades and discs, bearings and bearing housings, and combustor liners. All of these had been needed for engine rebuilds in FSED, and it was obvious that they would be needed again. Without these parts on order for rebuilds, it would be necessary to steal parts from new production engines, which would delay the delivery of new engines and hence the delivery of new tanks.

Upon investigation, the author was told that some of the parts had been deleted because their leadtime was longer than one year and they were expensive. Leadtimes can be reduced with effort, and the author was concerned that, without those parts, there could be delays to the test program. His memorandum (Appendix E-1) addresses the problem and lists the critical parts he identified. Unfortunately, he left the program before the problem was resolved. It has been reported to him that the parts were not ordered and that delays in testing resulted.

Chapter 8

ALTERNATE ENGINES

Throughout the FSED phase of the program, with its engine problems, there were calls for development of an alternate engine, so that the entire tank program would not be delayed if the turbine engine were not ready for production. Some of these were legitimate, but others were inspired by the manufacturer of the diesel engine associated with the General Motors proposal which did not receive the contract.

1500 HP Diesel Engine

This manufacturer had a lobbyist in Washington who was very successful in generating concern about the development problems of the turbine engine. Through his efforts Congress appropriated $14.2 million for continued development of the diesel engine, and the diesel manufacturer attempted to make people believe that it could produce a production-ready, durability proven engine for that amount.

In fact, the funding would only complete development of the diesel engine, and provide for very limited engine durability testing. It was not adequate for any vehicle testing, nor for any of the vehicle redesign required to incorporate the diesel engine in the tank.

It was the author's position, supported by the Program Manager, that a true alternate engine program would be a massive and extensive undertaking requiring duplication of nearly all the testing which had occurred in FSED, since the engine was evaluated in all the testing. The vehicle would require a major redesign to accommodate the larger, heavier diesel engine and the different instrumentation. The transmission would require redesign for the lower input speeds from the diesel. Fire Control tests would have to be repeated to check vibration effects from the engine on the fire control system. Operational tests would have to be repeated to insure the troops could maintain and operate this new vehicle. Necessary production machinery would have to be procured in advance so the engine could be produced in quantity if it were eventually chosen.

The author estimated that the entire, realistic program (Appendices F-1 and F-2) would cost $230 million and take five years to complete, thus delaying production by about four years. Fortunately, such a program never occurred, and the tank went to production on schedule.

Other engines were also proposed as backups including existing aircraft turbine engines and the diesel engine used in the German LEOPARD II tank, which was being developed concurrently. To the uninitiated, one 1500 HP engine seemed much like another, and there was the widespread incorrect belief that it was a simple matter to substitute a different engine. The author evaluated many of these possible alternatives, and one of the most interesting was the use of the General Electric T700 helicopter turbine in the tank.

The T700 Helicopter Turbine Engine

The T700 is a 1250 HP turbine engine developed for dual installation in the Army's Blackhawk helicopter. Its development coincided with that of the AGT 1500 for the tank, and the question was raised concerning why the Army should develop two different engines of similar ratings. The author was tasked by the Program Manager to answer the question.

His investigation (Appendix F-3) highlighted the differences in the engines. The AGT 1500 had been designed from the beginning as a tank engine. It was configured to fit in the engine compartment of a tank and the power output was in the rear of the engine, so that it could mate with the transmission. It used inexpensive casing materials because weight was not as critical in the ground role. The T700 was designed as an aircraft engine. Its power output was at the front. It used exotic, lightweight, expensive casing materials. Its output speed was geared for an aircraft, not a ground vehicle. It had no recuperator to improve part-load fuel economy, and it was not designed to handle the accessory loads that were required for a tank. It used an air-start system powered by an auxiliary power unit instead of the electric start system used by the tank. The extensive modifications necessary to the T700 in order for it to be usable in the tank would have destroyed any commonality with the aircraft version of the engine. In addition to its lower power rating, which would have reduced the tank's performance, cost estimates placed it at approximately 50% more expensive than the AGT 1500.

Still, it was a legitimate, if somewhat uninformed question, and the author wrote and presented a briefing to senior officers in the Pentagon on the engine comparison (Appendix F-4). At the time (late 1977) the question was dropped, but about the time the author departed the program, General Electric proposed to the government a modification to the T700 that would be useable in the tank. To the author's knowledge, the proposal has not been acted upon.

Chapter 9

FOREIGN INTEREST

The development of a new tank, or any new weapons system, is extremely expensive. The development cost for the XM1 tank was over $250 million prior to production. Consequently, other friendly countries are often interested when a new weapon is being developed, and the XM1 was no exception. Germany, the United Kingdom, Japan, and Iran (prior to the revolution) all showed different levels of interest in the tank, and the author participated in several briefings with representatives of these governments.

Both the United Kingdom and Germany were developing tanks of their own at this time, and there was considerable interest in each other's design. Under NATO interoperability standards, it was a desirable goal if the same equipment were used by more than one country, thus simplifying logistics and reducing development costs.

The main problem with the development of a single tank for several different countries is that each country has its own slightly different tactical requirements for its tank, and the result has been that the differences between each country's design philosophies have been sufficiently great so that one country has not found the tank of another acceptable for its army. The US-German joint development of the MBT70 is an excellent example of a program, begun in the name of standardization, which failed because of differences in requirements and design philosophies.

Standardization of components is the next lower level, and both the United Kingdom and Germany showed interest in incorporating the turbine engine in their tanks. The author traveled to both countries and participated in technical feasibility discussions concerning adapting the turbine engine, and perhaps the transmission, to these other tanks.

British Interest

Two trips were made to London by the author to conduct briefings for the British Army on the possible use of the turbine powerpack in their new tank, the MBT80. On the first trip, in the fall of 1977, the author presented technical briefings on the XM1 and the turbine power pack and provided answers to questions (Appendix G-1)..

By the second trip, in late 1978, the British had modified their position to one of desiring the best possible powerpack for their tank, and standardization had become secondary. They were considering the bare turbine engine and transmission and intended to provide their own accessories and oil coolers so that the powerpack would fit in their vehicle. The other powerpack under consideration consisted of a British diesel engine and transmission.

During this second visit, the author coordinated the upcoming visit of the British to observe XM1 testing in the US and discussed the provision of a powerpack for them to test. Logistics, the results of current testing, and British plans were also discussed. As a result of these discussions it became very obvious to the author that the British were probably not interested in a standardized powerpack, but in one modified to fit their vehicle and with little interchangeability with the US version. Based on this, he recommended that the PMO become less directly involved but assist the British in coordinating with the engine and transmission manufacturer for possible production of their own version under license (Appendix G-2).

The British seriously studied the turbine powerpack, but their interest never progressed to the point where they requested one to test. Eventually they installed their own diesel engine and transmission in the MBT80.

German Interest

The United States had negotiated a Memorandum of Understanding (MOU) with Germany concerning interoperability of certain components of their new tanks. (The US had, in fact, tested the new German LEOPARD II tank as a possible alternative to developing a new tank, but it had not met the US requirements.) Part of the MOU stated that Germany would incorporate the turbine powerpack into its tank production when it met several unique German requirements.

The Germans were master negotiators and the unique requirements had been written in such a way that the turbine powerpack could never meet all of them. The author evaluated these requirements in the summer of 1977 and concluded that the Germans were not that serious about standardizing on the turbine (Appendix G-3). Their requirements were such that they wanted all the performance and interface characteristics of their own diesel engine in the form of a turbine, a requirements they knew the AGT 1500 could not meet. Certain requirements could never be met by the turbine powerpack, and others could be met only with significant modifications to the existing configuration.

In spite of the doubts concerning the sincerity of the Germans, plans were made to loan them a powerpack for installation in a modified prototype LEOPARD II tank. Modifications required to the tank for installation of the powerpack were minimal (Appendix G-4). The author accompanied German representatives on their visits to the contractors in preparation for the test, and made several trips to Germany in conjunction with it. The first trip, at the same time as the trip to London in the fall of 1977, was made to view the test facilities, provide answers to technical questions, discuss the German test plans, and view the modifications to the LEOPARD II (Appendix G-1). The Germans did a thoroughly professional job on the powerpack installation and vehicle modification, and it appeared to the author that it would be relatively simple to modify the production version of the LEOPARD II to accept the turbine powerpack.

The following year, the author observed the actual testing. The turbine powerpack performed well, and, unofficially, German engineers were very pleased with its performance, although the government would make no formal commitment to adopt it.

Throughout this period, the author participated, as the Program Manager's representative for the engine, in periodic meetings with the Germans on the subject of standardization. These meetings addressed, among other things, the unique German requirements. Although the Minutes of one of those meetings were encouraging (Appendix G-5), it became obvious that the Germans did not intend to adopt the turbine power pack. The author felt that the Germans had been using this opportunity to gain, at no cost, a great deal of turbine technology to which they had not previously had access.

In January, 1980, Germany formally declined to incorporate the turbine into their tank. Failure to meet all the unique requirements was given as the reason, but the real reasons were political. The "not invented here" syndrome was operating, and the German government could not adopt a American turbine engine, even though it would have been built under license in Germany, in lieu of a German designed and built diesel. Standardization, even at the component level, remains an elusive goal.

Chapter 10

OUTSIDE ASSISTANCE

Because this was the first use of a turbine engine in a ground vehicle by the Army, there was not a great deal of in-house expertise concerning turbine engines. Consequently the PMO received a considerable amount of outside assistance, both welcome and unwelcome, from various agencies. As the number of engine failures mounted, the level of outside assistance became almost unbearable.

Army Aviation Research And Development Command

The United States Army Aviation Research and Development Command (AVRADCOM) is responsible for the development of Army helicopters. At the Program Manager's initiative, AVRADCOM's help was sought, and they provided the most valuable continuing assistance. Mr. Ralph Tyson, an engineer for AVRADCOM, had many years of experience in the development and testing of small aviation turbines used in helicopters, and he assisted in the evaluation of engine failures and proposed design changes. Of all the assistance received, his was the most practical and useful because he was familiar with military requirements and knew what was realistically obtainable instead of insisting, as some "experts" did, on some unreachable ideal of performance.

Air Force

Early in the FSED phase, the Program Manager requested a visit from a team of turbine engine designers from the Air Force development laboratories at Wright-Patterson AFB, Ohio. They conducted a design review of the engine and provided recommendations on accelerated test programs.

During their initial visit it soon became apparent that their perspective was different from that of the Army. The officer heading the team was extremely concerned that the tank had only a single engine. From his viewpoint, a twin engine installation was much more desirable since his aircraft could still fly if one engine failed. He never quite accepted the fact that a tank crew could get out and walk if necessary, and that the complexities of a twin engine installation were not justified.

Secretary Of Defense's Review Panel

Due to the high number of engine failures during FSED, there was considerable concern at the Office of the Secretary of Defense (OSD) about the design maturity of the turbine engine. Consequently a panel was appointed by OSD in early 1979 to evaluate the engine design maturity and to make recommendations to increase confidence that it would be ready for production in 1980. The panel consisted of engineering and reliability sub-groups and was made up of senior executives from various industries, most with some experience in design of military equipment. Senior turbine engine designers from two major corporations were included in the panel, and a retired Army Lieutenant General was the operational evaluator for the panel. The author was the Program Manager's representative to the panel.

It quickly became obvious that, although the panel members were experts in their own fields, none of them, with the exception of the general, had any good idea of what a tank was, how it operated, what its missions were, or the environment in which the engine had to operate. The author's first task was to familiarize the panel members with these aspects. This objective was accomplished by a trip to Aberdeen Proving Ground to see the tank demonstrated and compared with the M60, the current tank (Appendix H-1). A demonstration of powerpack removal was also held, and this was the first opportunity that many of them had to see the tank and the engine. The designers on the panel were familiar with aviation turbines and had no concept of the dust levels in which the engine was required to routinely operate. They had no previous experience with air cleaners for turbines and were amazed at the dust, dirt, and grime which normally accompany tank operations.

The author accompanied the panel during its investigations, both at the engine manufacturer and at field sites, and participated in the technical discussions. He wrote and presented the briefings on the engine design, operation, and durability status, to include detailed test plans and explanation of engine failures (Appendix H-2). Once the panel members were familiar with the engine, they performed a good evaluation of the status of development and made several valuable recommendations which were subsequently implemented.

The author advised the panel concerning the feasibility of their proposed recommendations and attempted to insure that additional testing proposed by the panel would be not only realistic but also capable of being completed in the allotted time period and not in conflict with other program requirements. He helped design a "1,000 Hour" laboratory test for the engine which combined the NATO endurance test with a 600 hour mission profile test. He managed to convince the panel that while this was an excellent test of the engine, it was a severe overtest for the stated requirements, and successful completion of the test should not be a prerequisite for production. Instead, the results should be used to identify areas for future reliability improvements.

The panel concluded that the engine incidents were not unusual in a development program and that durability was about as should be expected for that stage of engine maturity. As well as additional testing, one of the panel's recommendations was that they reconvene in a year to assess progress made in the areas which they had identified. In the winter of 1980 the author again served as the Program Manager's representative to the panel. At this time the panel found that the engine and power train did meet the reliability and durability requirements, although areas for further improvement were identified.

General Accounting Office

The most unwelcome outside assistance came from the General Accounting Office (GAO) of the US government. A member of Congress had requested that the GAO evaluate the turbine engine and its readiness for production. In a GAO investigation any information requested by the investigators must be provided. Once a draft GAO report is written, it is customarily provided to the agency under investigation for review and correction of mistakes prior to being released.

The GAO investigators assigned to do this study were not familiar with turbine engines, tanks, or the army and were accountants, not qualified engineers. The author briefed them on several occasions, and his first step necessarily was to attempt to explain the workings of the engine to them. Many documents which the author had written were explained, discussed, and provided at their request. Engine failures and subsequent corrective actions were discussed at length. At no time during their investigation did they independently inspect the engines using qualified engineers, nor did they use the most recent laboratory test results in their report. They evaluated the engine against design goals instead of government requirements for reliability and durability. The investigators were also in touch with the competing diesel engine manufacturer and were apparently accepting, without proof, his claims as to the reliability of the diesel engine.

When the draft report was received for comment, it was found to contain many errors. Several problems which were cited as being current were, in fact, old problems which the investigators had been informed had been corrected. Quotes from PMO-provided documents were taken out of context or were misquotes. The competing engine manufacturer was given full credibility for his claims, and the documented test results for the XM1 and its engine were questioned. The report contained no recommendations for improvements to the engine or for additional testing, only for limitation of production and funding for alternate engines.

When the draft report was received for review, it was learned that it already had been released in Washington. The PMO was provided no opportunity to make corrections prior to the release of the document. Eventually, the corrections were made in the final report, but the inaccuracies in the first report received all the publicity and the corrections received none.

The author wrote many of the comments on the GAO report (Appendix H-3), and in testimony before Congress, General Keith, the Deputy Chief of Staff for Research and Development for the Army, used these comments as rebuttals to the report.

The general feeling was that the GAO was out to do a "hatchet job" on the turbine engine, and the high number of inaccuracies and general haphazardness of the report reinforced that belief. The Congressman who had requested the report was from the district in which the diesel engine manufacturer's plant was located.

The author compared the OSD panel report and the GAO report and found a significant lack of professionalism on the part of the GAO (Appendix H-4). The generally low quality of the GAO's work was a disappointment to the author, but not really a surprise as he knew of other agencies and programs which had had similar experiences. It illustrated the difficulty of using non-engineers to evaluate what was primarily an engineering problem. A major concern to the author from this is that the general public believes the GAO reports, and the program had difficulty recovering from the inaccuracies presented in the report. Even today the author encounters people whose beliefs about the tank and engine are based on that report.

Chapter 11

OBSERVATIONS

The author's assignment to the Program Manager's Office was professionally extremely rewarding. He developed, over the course of his assignment, a great deal of expertise on the engine and the tank. He had a wide variety of professional experiences and the satisfaction of knowing that his efforts had a positive influence on the success of the tank program. The fact that his assignment coincided with the FSED phase of development enabled him to see the program progress from a single prototype tank to the beginning of production. The problems that were encountered and he helped to overcome gave him a tremendous sense of accomplishment, and, of all his assignments, this was also the most personally rewarding.

The author learned a tremendous amount during this assignment about many areas of engineering and program management. He took many impressions with him when he departed, and they dealt with various aspects of his experiences, both technical and nontechnical. A few of those impressions follow.

Interface Problems

One of the major problems with the engine was dust ingestion during testing at Ft. Bliss. Chrysler had responsibility for the air cleaner and the interface with the engine. AVCO Lycoming's responsibility was for the engine only. On the basis of the experiences, it would seem prudent that the responsibility for critical systems which must operate successfully together should be given to one or the other of the firms involved.

In that way, there will be no interface disputes to be resolved between a contractor and a subcontractor. In retrospect, design changes to the air filtration system would have occurred faster if AVCO Lycoming had had the responsibility for it as well as the engine. If AVCO had been given the responsibility for the air cleaner, they would have acted very quickly to solve any problems in order to protect their reputation. As it was, AVCO Lycoming received much of the bad publicity for a Chrysler problem.

Concurrent Development

In order to provide the most modern equipment for the army, major components were still being developed during FSED at the same time as the tank was being tested. This is not unusual for weapons system development, but it can complicate programs. The engine, transmission, and fire control system were still in the final stages of development during FSED, and as problems were discovered, design changes were made and incorporated as quickly as possible into the components so that they could be at least partially tested.

A more conservative design philosophy would have been to use proven, fully developed components for the new tank, but this would have resulted in an obsolescent system by the time it was produced. This philosophy results in nothing more than product improvements on existing systems, and there comes a time when improved technology is not adaptable to current equipment and a totally new design is required.

Such was the case with the XM1. It would have been impossible to incorporate the "special armor" into the existing M60 tanks, and it would have been nearly impossible to modify the M60's suspension and to install a more powerful engine which would allow the tank to reach a top speed of 45 MPH.

Concurrent development increases the risks of a program, but the risks are necessary in order to insure the best, most modern equipment. Decision-makers should be aware that problems will occur and should make allowances for that when they are evaluating a new system. The impression that the author had was that senior officials did not like to hear of any problems.

Concurrent Testing

Because of the Congressionally imposed seven year development period, the FSED phase was compressed. It was impossible to reduce the time required for the competitive first phase, so the FSED phase was shortened. As previously stated, the contractor had no opportunity to "wring out" his new vehicles prior to turning them over to the government for Development and Operational testing. Consequently, many problems were initially discovered during the government testing, and it was necessary to halt the testing several times for vehicle modifications so that the latest design changes could be incorporated.

Because of the compressed schedule and the necessity for government testing to precede contractor testing, the scoring methodology used allowed for the discounting of early failures if design modifications had been made, incorporated in the tank for a significant portion of the test, and the failure mode had not recurred. This discounting of failures was done at formal scoring conferences, and a majority of the voting representatives from the various agencies had to agree before a failure was discounted.

The major problem with this procedure was that there was no agreement as to how much testing was required to prove a design change. It seemed that everyone had his own opinion. The contractor generally felt that a change needed little or no testing, the test agency felt that it needed an entire new test, and the final decisions were usually subjective.

In spite of this difficulty, it seemed to the author that this was an excellent method for insuring that the latest version of the tank was being evaluated, but outside agencies, such as the GAO, apparently did not fully understand the method and severely criticized the procedure. They claimed that the PMO was not counting many failures which had occurred, and therefore the durability and reliability figures for the tank were not correct. These criticisms reached the media, and more unnecessary bad publicity resulted.

It is easy to be a critic, especially if the criticism is not based on all the facts, and it is very difficult to defend against. The Program Manager was continually put in the position of having to defend the test results and the scoring procedure and explain the true situation. Not only does this take a great deal of time, but rebuttals always seem a little lame to the outsider, and there is a tendency for him to believe the first report.

Reasons for Testing

There are two reasons to test a weapons system prior to production, and the two are not compatible. At the end of the FSED phase a high level decision is made as to whether the system is ready for production. The results of the testing are a major factor influencing that decision, and production on some programs has been cancelled or delayed based on unfavorable test results.

The first reason to test is to discover the problems with the system while it is still in the prototype stage so that they can be corrected prior to production. This reason would lead one to design a very rugged test of the system in which many failures and problems would be expected to occur. There might even be test delays while modifications are incorporated into the vehicles for the remainder of the test. Because there may be many failures the system may receive unfavorable publicity which could prejudice the public and decision makers. If the test is too rugged, the system may never be allowed to enter production. The end result, however, would be that when the system did enter production most of its problems would already have been solved and the user would have a superior system.

The second reason to test is so that the system can be given permission to enter production. This would lead one to design an easy test for the system. If there are few problems or failures during the test, the decision maker has an easy choice and the system will probably enter production. However, the result may be a vehicle which still has many problems remaining in the production version. This leads to expensive modification programs, and possibly reduced systems effectiveness.

This, then, is the dilemma. Where, between the extremes, should the test be designed? What is the right balance to strike so that an excellent, fully tested vehicle will actually be produced? The XM1 took the rugged test extreme, somewhat by chance, and the production program was nearly delayed or cancelled several times. The testing paid off, however, and reports from the field state that it is an excellent tank, far better than anything the Soviets have and that there is no comparison between it and the M60. The soldiers who use it, and may someday have to fight in it, like the tank and its capabilities, and that is the ultimate test.

Politics and Reality

Political considerations often override the reality of the situation. The lobbyist for the diesel engine manufacturer which did not receive the contract and the Congressman for that firm's district were able to induce Congress to appropriate $14.2 million for a "diesel backup program". This program has already been discussed, but the funding was unnecessary based on the ongoing test results, and it was inadequate for its stated purpose of "finishing development of a production ready backup diesel engine".

It amounted to a political gift to assist this firm, which had lost the competition, from the government. To the author, it seemed a great waste that the funds were spent in this manner. If the success of the tank program were the real issue, the funds could have been spent much more profitably to improve the turbine engine or some other component of the tank. However, politics does not operate in that manner, and in the author's opinion, the money, which was taxpayer's money, was not wisely spent. The author does not know how, with our form of government, such occurrences can be avoided.

Experts and Consultants

The author had many dealings with consultants to the program and outsiders brought in for their expertise on turbine engines. They were supposed to use their knowledge to provide assistance to the program. However, the author discovered that, generally, they brought little knowledge of the particular problem with them and it was necessary to educate them before they were productive.

The value of spending time and effort educating them and then having them confirm what was already known seems questionable. Its real value comes from building a body of opinion to reinforce what the PMO already knows. This assists the decision makers and gives them more confidence in their decision. As such, it is a necessary evil of the development process.

Decision Makers

As in any bureaucracy, there were many groups and agencies which had little directly to do with the success of the tank program, but which could meddle in it. There were obscure requirements and regulations which the program must comply with but which did not benefit the program, and these agencies felt that the tank program should not continue until their interests were considered.

The result was that there were many people and agencies which could delay or hinder the program, but there was no one single person or agency which could say, "Proceed at full speed. This system is needed as soon as possible." There are so many checkpoints and milestones in the development process and so many agencies are involved, that is is extremely easy to delay a program but nearly impossible to expedite it.

It routinely takes seven to ten years to field a major new weapons system, but World War II was fought and won in only three and a half years. Other countries can develop and field equipment in less time, and the development process must be streamlined and simplified in order to reduce development costs and to make the system more responsive.

Communications

Perhaps the most frustrating problem the author encountered was that of communicating engineering information to non-engineers. When a failure occurred, the news traveled quickly. The author found that many people, especially at high levels of government, were only interested the fact that a failure had occurred. They were not interested in, and, in many cases did not attempt to understand, the technical reason for the failure. Consequently, they were not interested in and made no attempt to understand the corrective action which was being taken. The author felt that these people's opinion was, "It broke, therefore it's no good, and you are just trying to alibi the problems." It was obvious that they did not understand the reasons for testing and were not interested in learning.

In all the author's dealings, he seldom was able to truly communicate with these people, and it remains a serious problem, since some of these people are the ones who decide the fate of major programs and are the ones who should be capable of making informed decisions.

REFERENCES

Department of the Army Regulation 70-17, Program Management, Department of the Army, Washington, DC, 1981.

"Doctor of Engineering Program Manual", College of Engineering, Texas A&M University, undated.

"Program Manager Charter for the M1 Abrams Tank System", Department of the Army, Washington, DC, 13 April 1981.

APPENDIX A

Appendix A-1

DRCPM-GCM

Automotive Branch
9 September 1977

ENGINE FACT SHEET

1. Background:

a. Nomenclature: AVCO Lycoming Gas Turbine Engine: AGT 1500.

b. Requirement: Vehicle performance requirements were specified in the MN and were met or exceeded using the AGT 1500 engine in the XM1:

Characteristic	MN Requirement	XM1 DT I Results
Acceleration 0-20 MPH	6-9 Sec.	6.2 Sec.
Max. sustained speed	35-40 MPH	44 MPH
10% slope speed	20-25 MPH	24 MPH
60% slope speed	3-5 MPH	5.2 MPH

2. Characteristics:

a. Engine Schematic: See Inclosure 1.

b. Tabulated Characteristics:

Dimensions	
Length	66.75 in.
Width	39.0 in.
Height	31.6 in.
Dry Weight (excluding starter and hydraulic pump)	2475 lbs.
Governed Maximum Output Speed	
Normal	1500 shp at 3000 rpm
Required for 45 MPH vehicle speed	1000 shp at 3100 rpm
Neutral	0 shp at 2620 rpm
Required for 5 RPM vehicle rate of pivot	1100 shp at 2400 rpm
Governed Minimum Output Speed	
Low idle	0 shp at 890 rpm
Required for vehicle creep speed of 2.5 mph	85 shp at 870 rpm
Tactical idle	0 shp at 1350 rpm

Oil Capacity including 2 gal. cooler and line capacity	7 gals.
Oil Consumption (not to exceed rate after 100 hours of operation)	0.1 gals. per hr.
Fuel Types	DF-2, DF-1, and DF-A Diesel Fuel JP-4, JP-5, Jet Fuel, gasoline (emergency)
Best Specific Fuel Consumption	0.475 lbs. per hp hr.
Transient Response (from idle to 90 percent rated power)	2.5 sec.
Power Decay Rate (from 100 percent rated to 20 percent rated power)	2 sec.
Exhaust Smoke	No visible smoke
Engine Noise Level (at 50 ft. and vehicle traveling 20 MPH)	101 db

c. Description: The AGT-1500 tank turbine engine features a two-spool gas producer, a free power turbine output, and a recuperator for maximum efficiency throughout the operating range. All components have been conservatively designed for maximum structural integrity and simplicity. The engine-mounted accessories are arranged for ease of removal and replacement with the power package installed in the vehicle. The engine control system is designed for operational simplicity and features automatic engine protection.

The basic AGT-1500 engine configuration is represented schematically in Incl 1. The two-spool gas producer is made up of two independently rotating sets of compressors, a low pressure set and a high pressure set, with each set driven by a single stage axial turbine. The engine air flows axially into the low pressure compressor where the pressure is increased by five axial stages to approximately 48 psia at full power. The flow continues through the high pressure compressor, which has four axial stages and a single stage centrifugal compressor with a radial diffuser, where the pressure is further increased to its maximum pressure of 197 psia. The compressed air then passes through a recuperator (stationary air to air heat exchanger) where the compressed air is partially heated by recovering waste heat from the exhaust gas, thus reducing the amount of fuel subsequently required to heat the air. The air then enters the combustion zone where fuel is

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Engine Fact Sheet (Cont'd)

introduced by means of a single spray nozzle and can combustor, which further increases the air temperature to approximately 2,180°F at maximum power. This heated gas expands through the high and low pressure turbine stages, which drive the respective high and low pressure compressors. Because of the work done by the turbines, the temperature and pressure at the exit of the low pressure turbine are reduced to 1,458°F and 42 psia respectively at maximum power. The air is further expanded through a two-stage power turbine that delivers power to drive the vehicle as well as transmission-mounted accessories. The gas then flows through the recuperator and heats the compressor discharge air as indicated previously. The exhaust temperature, as the gas exits the recuperator, is 944°F maximum.

The two independently rotating gas-producer compressors and free power shaft serve to improve operating efficiency of the engine at both the rated design point as well as part load. If the two gas-producer compressors were directly coupled to operate on a single shaft, the forward low pressure compressor stages would operate inefficiently at part power. Since the free power turbine also rotates independently from the other main shafts, this allows the gas-producer compressors to operate at optimum efficiency over the entire spectrum of torque and speed output.

To further improve power-turbine output efficiency and thereby maintain good fuel economy at part load, the engine features variable inlet nozzle vanes to direct the hot gases at the optimum angle on the blades of the power turbine wheel. The current AGT-1500 engine also incorporates variable inlet guide vanes that are primarily used to direct the incoming air flow to the first low pressure compressor rotor blading during starting and operation up to approximately 40 percent power. Above this power level the inlet guide vanes operate in one fixed position.

All of the engine-mounted accessories are located vertically on the accessory gearbox with the mechanical drive through gearing to the high pressure spool. The engine required accessories mounted on the accessory gearbox are the starter, oil pump and filter assembly, and fuel control. A spur gear train connects each of these accessories to the single shaft connected to the high pressure compressor shaft. The vehicle hydraulic pump is also mounted on a power takeoff pad on this same gearbox.

The output speed from the power turbine is reduced through an integral reduction gearbox before transmission input.

The engine is designed in three major module assemblies: the forward module, the rear module, and the accessory gearbox module. This concept permits repair of the engine by changing only the failed module.

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Engine Fact Sheet (Cont'd)

9 September 1977

The engine system also includes a remotely mounted electronic control unit, a part of the electronic fuel management system, for automatic starting, engine control and protection, and governing of minimum and maximum output speed.

3. Schedule:

a. Engine durability testing is at Incl 2 and 3.

b. Engine delivery is at Incl 3.

4. Present Status:

	At End of Validation	Scheduled for FSED
Engines built	32	20
Total engine hours	11,500	18,600
Total engine miles	23,100	97,700

5. Cost:

a. FSED Contract: 20 new engines @ $748,000 each plus seven rebuilt Validation engines.

b. Production Unit Cost: Ten year average DTC engine price (AVCO selling price to Chrysler) is $110,479 (Dec 75$). This is based on 3312 engines and will change with the new quantity recommended at ASARC.

6. Personnel:

a. Man loading:

	FY77 (2 months)	FY78	FY79	FY80 (2 months)
Max	321	379	190	94
Min	267	191	99	77
Avg	294	272	138	86

b. Number of people at AVCO Lycoming: Approximately 3000.

7. Risk:

a. Technical: Technical risk is low. The engine has already met or exceeded performance and durability goals set for it.

b. Schedule: Schedule risk is low, but the schedule bears close watching. AVCO has a success-oriented engine lab test schedule and has already considered slipping some test milestones. Chrysler had scheduled

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Engine Fact Sheet (Cont'd)

8000 miles on engine S/N 26 in the ATR at Chelsea Proving Ground last Spring. Vehicle problems allowed them to accumulate only 3327 miles before a scheduled engine rebuild. In May-Dec 78 two vehicles are scheduled to run 9000 engine durability miles each. This is adequate time provided there are few problems, but the test must be monitored closely to insure Chrysler does not fall behind.

c. Cost: Cost risk (ten year average DTC) is moderate. This is based on the fact that the method used to arrive at the ten year average cost is questioned by the Cost Information and Analysis Branch, and the cost reductions claimed by AVCO due to productionalizing the engine, product improvements, etc., have not been completely planned, identified and scheduled for introduction into the engine.

8. Previous Guidance/Interest:

a. Higher echelon: DoD was greatly interested in the engine choice for XM1. During the source selection process, DA and DoD engine Review Committees were formed to evaluate the turbine and diesel engines. The ASA (RD&A) requires bi-monthly engine status briefings. DCS (RD&A) is interested in cost comparisons between the T700 engine (used in UTTAS) and the AGT-1500 and was briefed on this subject.

b. User: The user is basically unfamiliar with gas turbine engines. An education program may be necessary. Armor Branch aviators need to be informed of differences between the AGT-1500 and aircraft turbines.

	Max Power	Idle
Shaft Horsepower	1500	35
Mass Flow ~ lb/sec	12.1	3.0
N_H ~ RPM	43900	24400
N_L ~ RPM	31500	11900
Output Shaft Speed ~ RPM	3000	400
Low Compressor Efficiency Adiabatic ~ %	85.0	
High Compressor Efficiency ~ Adiab. %	79.5	
High Turbine Efficiency ~ Adiab. %	83.6	
Low Turbine Efficiency ~ Adiab. %	83.3	
Power Turbine Efficiency ~ Adiab. %	88.4	
Low Compressor Inlet Temperature ~ °R	519	519
Low Compressor Inlet Pressure ~ PSIA	14.7	14.7
Low Compressor Exit Temperature ~ °R	764	
Low Compressor Exit Pressure ~ PSIA	48	17
High Compressor Exit & Recuperator Air Inlet Temperature ~ °R	1250	
High Compressor Exit & Recuperator Air Inlet Pressure ~ PSIA	212	35
Recuperator Air Exit & Combustor Inlet Temperature ~ °R	1443	
Recuperator Air Exit & Combustor Inlet Pressure ~ PSIA	209	
~~Low~~ HIGH Pressure Turbine Rotor Inlet Temperature ~ °R	2560	

	Max Power	Idle
High Pressure Turbine Rotor Inlet Pressure ~ PSIA	203.0	
High Pressure Turbine Exit Temp. ~ °R	2119	
High Pressure Turbine Exit Pressure ~ PSIA	75	
Low Pressure Turbine Inlet Temperature ~ °R	2082	
Low Pressure Turbine Inlet Pressure ~ PSIA	75	
Low Pressure Turbine Exit Temperature ~ °R	1873	
Low Pressure Turbine Exit Pressure ~ PSIA	44.0	
Power Turbine Inlet Temperature ~ °R	1867	1393
Power Turbine Inlet Pressure ~ PSIA	44.0	
Power Turbine Exit & Recuperator Gas Inlet Temperature ~ °R	1534	
Power Turbine Exit & Recuperator Gas Inlet Pressure ~ PSIA	17.7	
Recuperator Gas Exit Temperature ~ °R	1361	
Recuperator Gas Exit Pressure ~ PSIA	14.7	
Reduction Gear Efficiency	98%	

Appendix A-2

DRCPM-GCM-SH 13 March 1980

REPLY TO QUESTIONS ASKED
BY SENATOR'S EXON AND WARNER

Question No. 2: How much shaft horsepower has the XM1 engine shown to date when connected to its air cleaners and exhaust ducts?

Response: Shaft horsepower is that power available at the output of the engine. The "bare" engine (without air cleaners or exhaust duct) is rated at 1500 shaft horsepower. Approximately 1280 shaft horsepower is available as measured in the laboratory with XM1 inlet and exhaust systems connected.

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REPLY TO QUESTIONS ASKED
BY SENATOR'S EXON AND WARNER

Question No. 3: Since this is a 1500 shaft horsepower engine does the Army expect to get that type of performance?

Response: Yes. A loss of shaft horsepower with inlet and exhaust systems connected is typical of any engine whether it is gasoline, diesel, or turbine.

Engines are typically rated for shaft horsepower as "bare" engines, that is, without inlet or exhaust attached. Most ground engine applications (automobile, truck, tank, etc.) require air inlet system for air filtration and an exhaust system to duct exhaust gases to an appropriate location and silence the engine noise. Therefore, the maximum installed shaft horsepower attainable will always be less than the rated shaft horsepower. Racing cars and dragsters are an exception and have little or no inlet or exhaust systems in order to maximize available shaft horsepower, but they operate for only short periods of time in a very restricted environment.

DRCPM-GCM-SH 13 March 1980

REPLY TO QUESTIONS ASKED
BY SENATOR'S EXON AND WARNER

Question No. 4: What has the diesel engine been tested to in shaft horsepower?

Response: The Teledyne Continental AVCR 1360 diesel engine is rated at 1500 Gross Horsepower. It is an air-cooled engine with integral cooling fans and the shaft horsepower available (power available at the output of the engine) is determined by subtracting the power required for the fans from the gross horsepower. At full power, the cooling fans require 160 horsepower, so the maximum shaft horsepower for the bare AVCR 1360 is 1340 SHP. To obtain the installed shaft horsepower, the power loss due to the air cleaners and exhaust for the diesel must be included. For the AVCR 1360 installed in a tank, this loss is approximately 200 HP, so the maximum available installed shaft horsepower for this engine is approximately 1140 SHP.

DRCPM-GCM-SM 13 March 1980

REPLY TO QUESTIONS ASKED
BY SENATOR'S EXON AND WARNER

Question No. 8: Has the turbine engine met the durability goals established for the production version of the XM1?

Response: Yes. The government durability requirement is established for the power train (engine, transmission and final drive) and is the same for full scale engineering development (FSED) and production: 50% probability of completing 4000 miles without a durability failure. Based on the 16,000 miles of Ft. Knox testing on three tanks, the power train achieved a 54% probability of 4000 miles without a durability failure.

.....-SCM-SM 13 March 1980

REPLY TO QUESTIONS ASKED
BY SENATOR'S EXON AND WARNER

Question No. 24: General Babers, in your personal opinion, is there a need to continue a backup-diesel-engine program for the XM1 in FY1981?

Response: No. The AGT 1500 turbine engine today is a mature, well-proven, extensively tested engine which meets all of the Army's performance, reliability, and durability requirements. Based on its demonstrated performance, there is no need to pursue a backup diesel engine program.

The AVCR 1360 diesel engine is neither mature nor ready for production. The funds appropriated by Congress would be primarily used to complete the development of the engine components, including variable area turbochargers (VAT), and variable speed cooling fans, and for reconfiguration of the engine to be compatible with the XM1 tank, including reconfiguration of the oil pan, relocation of the oil pump, alternator, hydraulic power supply and starter motor, and redesign of the accessory drive train. This XM1-compatible diesel would be a new engine configuration without any test experience or maturity. These major design changes to the engine induction system, lubrication system, cooling system and structural integrity require a complete development cycle to verify that vehicle performance and durability requirements can be met. USATARADCOM has stated that 3000 dynamometer hours and 50,000 vehicle miles are required, and at the end of that testing, there is no assurance that the diesel engine's performance, reliability and durability will be as good as the turbine engine is now.

Appendix A-3

DRCPM-GCM-SM 12 December 1977

MEMORANDUM FOR RECORD

SUBJECT: Trip Report

1. On 7 Dec 77 the undersigned visited AVCO Lycoming for the purpose of viewing the engine damage on engine S/N 26 which failed at APG on 3 Dec 77 while installed in FV-1.

2. The blades of the first stage HP compressor had failed (Incl 1). All blades of that stage had been broken and had disintegrated while passing through the remaining stages of the HP compressor. There was extensive damage to the remaining stages of the HP compressor. There was minor FOD to the LP compressor, but this is believed to be unrelated to the HP compressor failure.

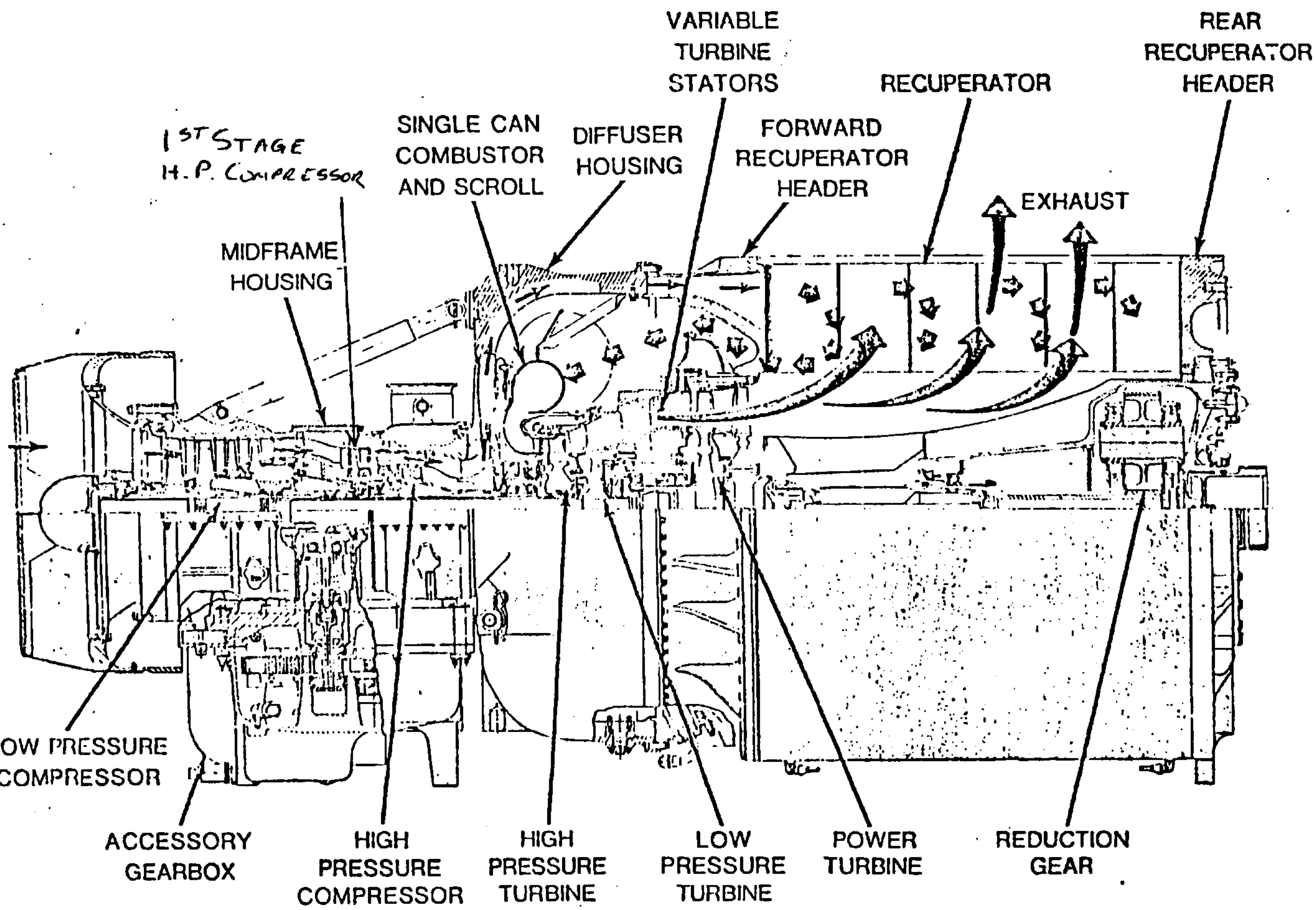
3. Preliminary examination showed evidence of fatigue cracks on the blade stumps of approximately 70% of the blades of the failed stage. Detailed analysis of the cause of the failure will require some time.

4. Details of the modifications to the engine fuel system necessitated by the recent problems are shown at Incl 2. The modification reduces the pressure drop accross the 'T' fitting and associated tubing at full flow rates from 12 psi to 1 psi. This appears to have solved the problem.

2 Incl
as

PAUL M. ROOT
MAJ, OrdC

AGT 1500 ENGINE SCHEMATIC



incl 1

Appendix A-4

DRCPM-GCM-SM

FACT SHEET

Automotive Branch
MAJ Root/31231
6 December 1977

SUBJECT: Engine Failure on FV-1

Project Manager, XM1 Tank System

PURPOSE. To inform the Project Manager of the facts surrounding the engine failure on FV-1.

FACTS.

1. On Saturday, 3 December 1977, FV-1 was running at APG when the engine, #26, "popped", shut down, and would not restart. First indications were that the problem was a dirty fuel nozzle. The engine had accumulated 718 hours (roughly equivalent to 7180 miles) prior to the failure.

2. When the fuel nozzle was replaced, four of the mounting bolts sheared. A new nozzle and combustor dome were shipped from AVCO and installed.

3. The engine started but "surged" at idle and was immediately shut down. The compressor bleed tube was removed and small pieces of metal were visible, indicating compressor damage, possibly due to Foreign Object Damage (FOD).

4. Engine #27, a Validation engine with FSED update previously used for AVCO in-house lab testing, was shipped to APG and arrived at 0130 Monday, 5 December. The engine was assembled to the transmission and ground hopped Monday night and installed in the vehicle and checked out Tuesday morning, 6 December. FV-1 was scheduled to run late Tuesday afternoon.

5. Engine #26 was shipped to AVCO and the failure is being analyzed. Preliminary inspection revealed compressor damage to several stages including what appears to be FOD to the first stage low pressure compressor. AVCO is performing a detailed metallurgical analysis of the damaged parts to determine the cause of failure. Results should be available within a week.

6. AVCO estimates that engine #26 should be repaired within ten days and can then be reinstalled in FV-1.

E. W. TRAPP
C, Sys Engr Div

PROJECT MANAGER ACTION:
NOTED: ____________
SEE ME: ____________

Appendix A-5

DRCPM-GCM-SM

FACT SHEET

Automotive Branch
MAJ Root/31231
27 April 1978

SUBJECT: Circumstances Surrounding the Government's Delay in Accepting PV4

Project Manager, XM1 Tank System

PURPOSE: To chronicle the events leading to the PM's refusal to accept PV4 prior to inspection of the engine #4 bearing forward seal.

FACTS:

1. On 5 January 1978, testing of engine #28, a rebuilt validation engine, was temporarily suspended due to metal chips found in the engine oil. Chip detectors revealed the problem before secondary damage occurred. The cause was damage to the forward oil seal of the rear compressor support bearing (#4 bearing) which had been pressed too far into its support housing. The engine #4 bearing package had been redesigned for FSED and engine #28 had been modified to incorporate the new design.

2. The proper assembly of the seal is shown at TAB A. The seal assembly should be pressed into the housing until it contacts the snap ring. A special tool is supposed to be used behind the snap ring to prevent the seal assembly from being pushed in too far. The fit between the seal assembly and its housing is .003" interference, so once it is installed, the seal should not move.

3. If the seal assembly is improperly installed (see TAB B) and is pressed too far into its support housing, high loads result between the seal carbon element (#1) and the seal runner (#2). This is due to the fact that the carbon seal element is fully compressed on its springs (#3). If the engine continues to run, the seal will be damaged (heat and high wear) and bearing damage will eventually result due to metal chips from the seal getting into the bearing (see TAB C). Eventually bearing failure will occur, and due to the thrust load applied to the high pressure compressor shaft which tends to displace the compressor shaft longitudinally, extensive secondary damage can result to the HP compressor.

4. In order for this situation to occur, the seal assembly must be pressed in past its locating snap ring, displacing the snap ring by forcing it out of its locating groove. This indicates that the special assembly tool was

not used during assembly. There is a very small tolerance where the seal assembly can be pressed in far enough to displace the snap ring but not far enough to fully compress the seal element springs. This condition indicates improper assembly, but in this case, damage would probably not occur due to the fact that the seal springs are not fully compressed and the resultant loads between the seal runner and the carbon element are not too high.

5. After this problem appeared on engine #28, all FSED engines subsequently manufactured had a specific inspection for proper installation of this seal assembly. Five FSED engines had been manufactured and shipped to Chrysler prior to the incident on engine #28. They are #33, 34, 35, 37, and 38.

6. On 4 April 1978, engine #34, installed in FV-4 at APG, suffered a failure of the #4 seal assembly. Secondary damage to the high pressure compressor also occurred. Investigation revealed that the #4 forward seal assembly had been pressed in too far, dislocating the snap ring and causing damage as described above. At that time, AVCO began planning to check the remaining four engines for proper seal installation. The engines were installed in P1, P2, P3, and P4.

7. On 11-12 April, Major Root was at AVCO for technical discussions including discussions on the #4 bearing seal assembly. During a telephone call on 12 April with Mr. Irvin Smith, it was realized P4, with engine #38 installed, was due to be delivered to the Government without the #4 seal assembly having been inspected for proper installation. The PMO refused delivery of the vehicle. The front module from engine #43 (the seal had been inspected) was substituted for the front module of engine #38 and the vehicle was accepted by the Government one day late. At this time, two failures had occurred (#28 and 34) and the other engines had not yet been inspected (#33, 35, 37, and 38).

8. On 17 April, Major Root visited AVCO to observe the disassembly of the #4 seal assemblies on engine #38 (from P4) and #37 (from P3). The assembly from #38 was properly installed as evidenced by flow and vacuum checks of the assembly and by dimensional measurements. The assembly from #37 was improperly installed. Dimensional checks showed it was pressed slightly too far into its housing and the snap ring was displaced. It was not pushed in so far that the seal springs were fully compressed as described in para 4. At this point, two engines had failed and one of the two others inspected had an improperly installed seal.

DRCPM-GCM-SM 27 April 1978
SUBJECT: Circumstances Surrounding the Government's Delay in Accepting PV4

9. Engines #33 (from P1) and 35 (from P2) are still to be inspected.

3 Incl
as

WPD E. W. TRAPP
C, Systems Engineering Division

PROJECT MANAGER ACTION:

NOTED:________________

SEE ME:________________

Appendix A-7

Automotive Branch
MAJ Root/31231

DRCPM-GCM-SM | FACT SHEET | 27 September 1979

SUBJECT: Turbine Engine Failures

Program Manager, XM1 Tank System

PURPOSE: To identify failure modes of field engines.

FACTS:
1. Since the 6 August 1979 update, four engines have been removed for repair.

2. The total number of engine replacements is now 39 failures and 14 engines removed prior to failure.

3. Recapitulation of failure causes:

a. Cause (attributable to):

(1)	Dust erosion (air induction system design)	9(2)
(2)	FOD (human error)	2(1)
(3)	LP turbine shroud (quality)	2
(4)	#4 seal assembly (engine design)	1
(5)	Combustor dome lip (engine design)	1
(6)	Compressor surge (engine design)	2
(7)	Overfuel/low voltage start (fuel control design)	4
(8)	LP turbine wheel/blades (engine design)	2
(9)	Burned combustor scroll (engine design)	2(2)
(10)	Accessory gearbox bearings (three engine design, one quality, one under investigation)	5

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SUBJECT: Turbine Engine Failures

(11)	#6 bearing (secondary failure - fording kit)	1
(12)	#7 bearing seal assembly/piston rings (engine design)	(2)
(13)	#3 bearing/seal (under investigation/quality)	1(1)
(14)	Crew error, maintenance error, abuse	6(2)
(15)	Burned nozzles (under investigation)	(1)
(16)	PTS linkage/recuperator cracking (quality)	(1)
(17)	HP turbine blade (under investigation)	1
(18)	#10 bearing seal (under investigation)	(1)
(19)	Power shaft piston rings or seal (under investigation)	(1)

b. Summary:

(1)	Air induction system design	9(2)
(2)	Engine design	11(4)
(3)	Fuel control design	4
(4)	Quality	3(2)
(5)	Crew error, maintenance error, abuse	6(2)
(6)	Under investigation	3(3)
(7)	Other	3(1)

( ) Denotes removal/replacement prior to failure.

4. Explanation of recent failures is at Inclosure 1.

5. Breakout of all failures by test type is at Inclosure 2.

EW Trapp
E. W. TRAPP
Chief, Systems Engineering Division

2 Incl
as

PROGRAM MANAGER ACTION:
NOTED:__________
SEE ME:__________

ENGINE FAILURES SINCE 6 AUGUST 1979

1. On 13 August 1979, Engine #50 in P7 at Ft. Knox suffered a failed #3 bearing assembly. The cause of the failure was traced to oil contamination by aluminum oxide, an abrasive material. The aluminum oxide came from the engine oil cooler. The cooler had been improperly cleaned by a vendor for Chrysler in May during the vehicle overhaul and aluminum oxide formed in the cooler due to a reaction between the cleaning solvent (trichlorethane), water, and the aluminum cooler. Both engine and transmission oil coolers had this contamination and engine and transmission filters immediately clogged when the power pack was operated. Filters were changed and the lube systems were flushed thoroughly when the vehicle reached Ft. Knox. Subsequently, the transmission failed because the aluminum oxide had scored the turbine driven control pump. Evidence shows that the engine oil filter was on bypass during part of the initial operation which allowed aluminum oxide to contaminate all bearings and seals. After the engine failure, aluminum oxide was found in the other bearings. The conclusion is that the aluminum oxide damaged the #3 bearing which eventually failed. This is classified as a maintenance error.

2. On 23 August 1979, Engine #33 was removed from P5 at Ft. Knox as a precaution. The engine oil cooler was leaking and replaced with one from stock. On the second start excessive smoke was seen coming from the engine. Inspection revealed that the oil filter and in line screens were clogged. It was determined that the oil cooler had been improperly cleaned and had aluminum oxide in it which clogged the filters (See above.) To prevent a future engine failure, the engine was shipped to AVCO for complete flushing of the lubrication system and replacement of all bearings and seals. This is classified as a maintenance error.

3. On 8 September 1979, Engine #33 suffered a failed #3 bearing at Ft. Knox after only a few hours of operation since bearing replacement (see above). Bearing quality or improper assembly are possible causes, but the incident is still under investigation.

4. On 25 September 1979, Engine #33 suffered a failure of the bevel gear shaft, which drives the accessory gearbox, in the vicinity of the #12 bearing. The #12 bearing was destroyed and the spline shaft below it was distorted. This occurred after only a few hours of Ft. Knox operation after the previous rebuild (see above). This incident is under investigation.

TURBINE ENGINE FAILURES - DT II

DATE	VEHICLE	ENGINE	LOCATION	CAUSE	ATTRIBUTABLE TO	CORRECTIVE ACTION SEE NOTE
8 Jul	P1	A48	Yuma	Dust erosion	Air inlet system design	A
14 Jul	P9	A45	APG	Low pressure (LP) turbine nozzle shroud	Quality control (repaired on site)	B
23 Sep	P10	A37	APG	Dust erosion	Air inlet system design	A
30 Oct	P10	A34	APG	Foreign Object Damage (FOD)	Human error-removed prior to failure during scheduled maintenance.	K
8 Dec	P9	A45	APG	Compressor surge	Engine design	P
11 Dec	P9	A34	APG	Compressor surge	Improper repair	Q
14 Dec	P8	A47	APG	#6 bearing failure	Failure of deep water fording kit	S
8 Mar	P7	A33	APG	LP turbine blade	Engine design	Y
8 Mar	P9	A38	APG	#12 and 14 accessory gearbox bearing	Quality/engine design	GG
20 Mar	P2	A46	APG	#3 bearing assy seal	Quality - removed prior to failure	Z
10 Apr	P6	A42	APG	Accessory gearbox bearing	Engine design	U
18 May	P8	A48	APG	PTS linkage/recuperator crack	Linkage. Quality - removed prior to failure - cause of crack undetermined.	CC
18 Jun	P10	A44	APG	HP turbine blade failure	Dust clogged blade cooling passages- under investigation.	DD
25 Jun	P4	A43	Ft. Knox	#10 seal leaked	Under investigation - removed prior to failure.	
30 Jul	P6	A46	APG	Power shaft seals leaked	Under investigation - removed prior to failure	HH

TURBINE ENGINE FAILURES - OT II

DATE	VEHICLE	ENGINE	LOCATION	CAUSE	ATTRIBUTABLE TO	CORRECTIVE ACTI SEE NOTE
9 May	P5	A36	Ft. Bliss	Burned scroll	Combustor drain system design	C
10 Jun	P4	A39	Ft. Bliss	Compressor surge	Engine design	D
26 Jun	P7	A38	Ft. Bliss	Dust erosion	Air inlet system design	A
1 Jul	P2	A35	Ft. Bliss	Dust erosion	Air inlet system design	A
7 Jul	P4	A33	Ft. Bliss	Dust erosion	Air inlet system design	A
20 Jul	P4	A46	Ft. Bliss	LP turbine nozzle shroud	Quality control	B
1 Aug	P6	A39	Ft. Bliss	Dust erosion	Air inlet system design	A
4 Aug	P7	A43	Ft. Bliss	Dust erosion	Air inlet system design	A
18 Aug	P2	A41	Ft. Bliss	Dust erosion	Air inlet system design - removed prior to failure	A
24 Aug	P4	A35	Ft. Bliss	Overfuel during start up with low voltage	Fuel control design	E
12 Oct	P7	A50	Ft. Bliss	Dust erosion	Missing part of air cleaner V-pack - improper maintenance	L
16 Oct	P2	A36	Ft. Bliss	Burned scroll	Combustor drain design - removed prior to failure	I

TURBINE ENGINE FAILURES - OT II (cont.)

DATE	VEHICLE	ENGINE	LOCATION	CAUSE	ATTRIBUTABLE TO	CORRECTIVE ACTI SEE NOTE
25 Oct	P7	A33	Ft. Bliss	Compressor surge	FOD, high inlet restriction, inlet distortion-improper maintenance	J
3 Nov	P6	A38	Ft. Bliss	Dust erosion	Plenum seal cracked - insufficient clearance - air inlet system	M
17 Nov	P5	A39	Ft. Bliss	Broken LP turbine wheel	Fatigue - design	N
28 Nov	P7	A36	Ft. Bliss	Burned scroll	Combustor drain design - crew abuse	O
9 Dec	P4	A43	Ft. Bliss	Overfuel during start with low voltage	Fuel control design	R
15 Dec	P2	A35	Ft. Bliss	Dust erosion	Plenum seal improperly installed and V-packs damaged - abuse	T
18 Dec	P4	A37	Ft. Bliss	Accessory gearbox bearing failure	Engine design	U
3 Jan	P5	A50	Ft. Bliss	Burned scroll	Combustor drain design - removed prior to failure	V
22 Jan	P4	A31	Ft. Bliss	Burned scroll	Combustor drain design	V

TURBINE ENGINE FAILURES - OT II (cont)

DATE	VEHICLE	ENGINE	LOCATION	CAUSE	ATTRIBUTABLE TO	CORRECTIVE ACTIO SEE NOTE
23 Jan	P2	A50	Ft. Bliss	Excessive surging	Air inlet system - improper maintenance - removed prior to failure	W
28 Jan	P6	A42	Ft. Bliss	Leaky #7 bearing seal	Engine design - removed prior to failure	X
31 Jan	P6	A36	Ft. Bliss	Accessory gearbox bearing	Engine design	U

TURBINE ENGINE FAILURES - OT II (cont)

DATE	VEHICLE	ENGINE	LOCATION	CAUSE	ATTRIBUTABLE TO	CORRECTIVE ACTI SEE NOTE
23 Jan	P2	A50	Ft. Bliss	Excessive surging	Air inlet system - improper maintenance - removed prior to failure	W
28 Jan	P6	A42	Ft. Bliss	Leaky #7 bearing seal	Engine design - removed prior to failure	X
31 Jan	P6	A36	Ft. Bliss	Accessory gearbox bearing	Engine design	U

TURBINE ENGINE FAILURES
CONTRACTOR TESTING

DATE	VEHICLE	ENGINE	LOCATION	CAUSE	ATTRIBUTABLE TO	CORRECTIVE ACTION SEE NOTE
4 Apr	FV4	A34	APG	#4 bearing seal	Engine design	F
1 Jul*	P10	A42	DATP	Combustor dome lip	Engine design	G
20 Jul	FV3	A36	Ft. Bliss	Dust erosion	Air inlet system design	A
15 Aug	FV3	A33	Ft. Bliss	Overfuel during start up with low voltage	Fuel control design	E
16 Aug	P10	A48	DATP	Foreign Object Damage (FOD)	Human error	H
15 Nov	FV3	A48	Ft. Bliss	Overfuel during start up with low voltage	Fuel control design	E
10 Mar	FV2	A37	Ft. Bliss	Dust erosion	Air inlet system - removed prior to failure	AA
28 Apr	FV4	A45	Ft. Knox	Burned nozzle	Under investigation - removed prior to failure	BB
4 May	FV3	A34	Ft. Bliss	Leaky #7 bearing seal	Engine design - removed prior to failure	X

*Prior to Government Acceptance

TURBINE ENGINE FAILURES
FORT KNOX EXTENDED DURABILITY/RELIABILITY TEST

DATE	VEHICLE	ENGINE	LOCATION	CAUSE	ATTRIBUTABLE TO	CORRECTIVE ACTION SEE NOTE
27 Jun	P2	A47	Ft. Knox	LP compressor (FOD)	FOD screen mounting bolt	FF
13 Aug	P7	A50	Ft. Knox	#3 bearing failure	Contaminated engine oil cooler-maintenance error	II
23 Aug	P5	A33	Ft. Knox	Bearing contamination	Contaminated engine oil cooler-maintenance error-removed prior to failure	JJ
8 Sep	P5	A33	Ft. Knox	#3 bearing failure	Under investigation	KK
25 Sep	P5	A33	Ft. Knox	#12 bearing-bevel gear shaft failure	Under investigation	LL

TURBINE ENGINE FAILURES

NOTES:

A. Dust erosion: Dust ingestion around poor seals on V-packs and plenum causes compressor erosion and subsequent engine failure. V-packs, seals, plenum lip and seal redesigned. Interior redesign installed/tested on pilots thru Dec 78. Production prototype design installed on vehicles Jan-Apr 79. Production air induction system to be tested on P2, 5, 7 and FV2 beginning June 79.

B. Low pressure (LP) turbine nozzle shroud: Shroud thickness not to specification. Quality control problem. All remaining engines checked and found OK.

C. Burned scroll: Puddle of fuel external to scroll ignited and caused damage. Puddle formed on combustor drain and should have drained out. Drain working subsequent to incident. Pack had been dropped during maintenance five days prior to failure. Appears due to inadequate drain design on overfuel starts. See Note V.

D. Compressor surge: IGV and compressor bleed have been rescheduled to prevent surge. First stage High Pressure (HP) compressor has been redesigned to withstand surge. New design extensively tested and in most engines.

E. Overfuel during low voltage startup: When attempting to start the vehicle with weak batteries, voltage can momentarily drop so low that the ECU senses a loss of electrical power and goes into Fault Mode III. This provides enough fuel for a "limp home" capability if the engine is running, but too much for starting. The engine is overfueled resulting in burning of the HP turbine blades and LP nozzle. AVCO/Chrysler/Bendix (fuel control manufacturer) have identified the cause and have modified the fuel control logic to eliminate the possibility of recurrence. An interim fix was on pilot vehicles which worked well at APG and was not connected at Ft. Bliss. Production fix is now on all vehicles. All failures occurred without protective circuitry connected.

F. #4 bearing seal: Seal redesigned and problem eliminated. New seals in all engines.

G. Combustor dome lip: Lip assembly eroded at high temperature and damaged engine. Assembly has been replaced by a high temperature alloy lip assembly in all engines.

TURBINE ENGINE FAILURES

NOTES: (cont)

H. FOD: Human error. Nut or item of similar size in air inlet plenum caused compressor damage.

I. Engine split by Army to replace faulty T_7 harness. Internal damage discovered although engine still ran. Burned scroll identical to previous incident (Note C). Additional damage included burned and cracked HP & LP nozzles and burned bellows on #5 and 6 oil bearing feed lines. Several start attempts had been made with inlet cover on prior to failure.

J. Air filter pressure sensor broken and V-packs "heavily clogged". This may have resulted in excessive inlet air pressure drop. Minor FOD. Severely damaged air splitter gave inlet air distortion. Combination could have led to surge. No dirt in plenum. See Note D. Damaged air splitter had been in vehicle for 50 hours of operation. It should have been replaced. Improper maintenance.

K. Engine was operating satisfactorily when FOD was noticed during scheduled maintenance. Repair was made on site for precautionary purposes. See Note H.

L. See Note A. Air induction system had been modified, but a V-pack spacer was missing allowing sand and dust to leak past V-pack seal.

M. New design plenum seal cracked due to insufficient clearance between plenum lip and accessory gearbox. Chrysler relieving this clearance in all vehicles.

N. Cast C101 LP turbine wheel broke during operation. Investigation revealed fatigue was cause. Fabricated turbine wheel design is released for production and is under test. Will eliminate fatigue failures.

O. Scroll burn through as in Notes C and I. Three incidents have occurred on Engine 36. Engine made repeated unsuccessful start attempts (ground hop) prior to failure contrary to published starting instructions.

TURBINE ENGINE FAILURES

NOTES:(cont)

P. Compressor surge. Engine had been in vehicle since July. Either due to dust erosion prior to air induction system modifications (Note A) or surge (Note D).

Q. Compressor surge. Due to improper repair of FOD (Note K) by AVCO at APG. Engine operated only a few hours after installation prior to failure.

R. Overfuel as in Note E. Repeated unsuccessful start attempts made prior to failure. Engine started, oversped, black smoke and failed. Low voltage protective logic not connected.

S. #6 bearing failed due to water induced thermal shock. Water entered engine through leaking exhaust duct of deep water fording kit and caused shrinkage of #6 bearing outer race. Bearing subsequently failed.

T. New style plenum seal improperly installed. Seal folded over in 5 o'clock position. This is difficult to do and easy to check. V-packs damaged. Holes through barrier filters and end plate bent and wouldn't seal. Cause of damage: Crew abuse and failure to follow maintenance procedures.

U. Accessory gearbox bearing failure. #13 bearing in accessory gearbox fails due to lack of preload which allows balls to skid. AGB input shaft may fracture and damage intermediate housing. Failure corrected by preloading #13 bearing with a "wave washer".

V. Burned scroll. Puddle of fuel external to scroll ignited and caused damage. Puddle formed on combustor drain and should have drained out. Drain working subsequent to failure. This failure appears when a successful start is achieved immediately after several unsuccessful start attempts and the residual fuel has not drained out. Redesign of drain system in progress.

W. Engine had modified IGV schedule and wide chord blades. Compressor had dust erosion and surged, but did not fail. Removed prior to failure. Middle V-pack seal was leaking - improper maintenance. Blueing was off nose of engine. It had been blued on 6 Jan 79 indicating severe dust ingestion since then.

TURBINE ENGINE FAILURES

NOTES: (cont)

X. Engine removed due to excessive oil consumption. Engine was functional when removed. Appears to be a failure of #7 seal assembly or adjacent piston rings on power shaft.

Y. Fatigue failure initiating at trailing edge of blade of cast LP turbine wheel led to failure of blade. LP turbine wheel has been redesigned with a forged disc and individual blades. Blade redesign has moved the high stress area from the trailing edge.

Z. Cylinder in which #3 bearing is mounted was bored .003" too deep. Bearing therefore seated too deep and seal did not properly contact bearing. Quality problem. Engine removed prior to failure.

AA. Dust erosion due to leakage past center V-pack seal. Deformation of air cleaner box allowed center V-pack to be loose. Design of air cleaner box has been changed to prevent deformation.

BB. Looking forward, HP nozzle blades burned away in 8-11 o'clock region. Hole in one LP nozzle blade. Cause under investigation. Engine removed prior to failure.

CC. Engine removed for surging while still operational. Investigation showed turnbuckle in PTS actuator linkage loose although it was safety wired - Quality problem. Also discovered crack in recuperator core. Crack not repaired but engine returned to field. Max power 1395 HP due to loss of air through crack.

DD. One HP turbine blade broke apparently due to stress-rupture. Cooling passage in blade believed to be clogged with sand/dust causing blade temperature to rise. At high temperatures blade has short stress-rupture life.

EE. Engine output shaft seal (#10 seal) developed an oil leak. Engine removed and seal replaced prior to failure. Cause of leak under investigation. Seal had 503 hours at time of failure.

FF. Engine suffered failure of IGV and 1st stage LP compressor blades. Cause was FOD from FOD screen mounting bolt. Bolt worked loose outside FOD screen and was caught between FOD screen and plenum. It worked its way to front of FOD screen where it was trapped between front of screen and plenum. Bolt broke wires in FOD screen, worked its way through and caused compressor damage. Engine repaired and returned to service.

TURBINE ENGINE FAILURES

GG. Failure of #12 bearing in accessory gearbox drive train apparently due to assembly problem. Quality at assembly. (#14 bearing also failed. This is fixed by wave washer preload.)

HH. Engine had over 450 total hours when experienced high oil consumption. Power shaft replaced in field and problem corrected. Piston rings or seal at rear of power shaft apparently caused problem. Related to #7 seal leaks (see X) as both are usually replaced. Still under investigation.

II. Failure of #3 bearing attributed to oil contamination with aluminum oxide from improperly cleaned oil coolers at vehicle overhaul. Contamination damaged bearing which eventually failed.

JJ. Engine lubrication system flushed and bearings and seals replaced due to aluminum oxide contamination from improperly cleaned oil cooler. No failure.

KK. #3 bearing failed after only a few operating hours since last rebuild. Cause may be improper assembly or defective bearing but is still under investigation.

LL. #12 bearing and bevel gear shaft failure after only a few hours of operation since rebuild. Cause under investigation.

Appendix A-7

Maj Root copy

DRCPM-GCM-SM

2 May 1978

MEMORANDUM FOR RECORD:

SUBJECT: Trip Report to Ft. Bliss to Investigate Engine Problems

1. On 25 April I went to Ft. Bliss to investigate the engine problems on P5 and P4. The engine on P5 (#A36) would not start and had been down five days. P4 (#A43) shut down as it was pulling into the maintenance building and would not restart.

2. Mr. John Petty (engine) and Mr. John Shacklock (manuals) of Chrysler and Mr. Ed Pelligrino (test engineer) and Mr. Bill Egan (ILS) of AVCO arrived at approximately the same time as I did. Mr. Pelligrino brought a modified ECU and a diagnostic box for the engine. The modified ECU will eventually be retrofitted on all engines.

3. P5 had become inoperative on 21 April. The problem appeared to be lack of fuel getting to the fuel nozzle. In the process of bleeding the system the starter was burned out. There was a delay of at least one day while a new starter was flown in. After the new starter was installed, the problem persisted. Bleeding the fuel system showed no fuel was getting to the fuel nozzle. Start attempts aborted in approximately three seconds. Ft. Bliss personnel had done troubleshooting by the manuals with test sets and had reached a dead end. Although it was not called for in the manuals, they then tried VESTS. This is not normally used in engine troubleshooting but did read "faulty ECU" and called for further tests with a multimeter. At this time the new ECU was not yet available. It was further determined that no fuel was reaching the fuel nozzle. Upon his arrival, Mr. Pelligrino put on the new ECU and again bled the hydromechanical unit of the fuel control. The engine started on the next attempt and sped up due to excess fuel left in the engine. It was shut down. It was again started and ran O.K. for 15 minutes. It was shut down, the old ECU reinstalled and again was started. The engine ran O.K. and was declared operational. The vehicle ran until Saturday when it would not idle properly in neutral. The trouble was traced to a faulty IGV feedback cable. None was on hand so one was flown in from AVCO on Sunday. The engine ran satisfactorily, but when reinstalled in the vehicle, a good seal could not be made at the air plenum-engine seal. The seal would not properly fit on the bottom and tended to slip off. The band clamp had worked out of its sleeve in the seal and must be recemented in there. Vehicle is not yet (1 May) operational.

4. On 24 April P4 (engine #A43) had shut down while in the maintenance area. After the initial shutdown the engine was restarted, the vehicle moved forward 15-20 feet, made a slight left turn and after return of the "T" handle to the center position, the engine shut itself down and the master warning and caution lights came on. Other lights came on after shutdown. Driver cranked engine using "starter only" for 15 seconds, let engine coast down and then tried normal start. The engine started, N_{PT} rose to 850 RPM and then the engine shut down. Several warning and caution lights came on. The driver attempted to start again and when it was apparent that the engine would not start, he shut it off. On the night of 25 April Mr. Pelligrino put the new ECU on P4 and attempted to start the engine. The engine cranked but it was obvious there was no fuel getting to the engine. The hydromechanical unit was purged in several places and fuel then reached the nozzle. A start attempt was made and the engine started and ran. After normal shutdown, the old ECU was reinstalled and the engine ran properly.

5. The cause of the problem is not exactly known. AVCO and Chrysler engineers were present during the attempts to start. An investigation should be made to determine the cause of the problem and its resolution. Removal of the "lightning" valve and installation of new ECU's may solve the problems.

6. On Wednesday, 26 April, I drove P4 and felt that the power might be low. The driver subsequently reported low power. It was decided to run a power check that evening using the Engine Organisational Test set to check out the system. AVCO was given permission to install a pressure guage in the fuel line at the hydromechanical fuel control. During installation of the guage, the in-line fuel filter was dropped and fell under the engine. Retrieval of this part necessitated pulling the power pack. After a delay in obtaining a wrecker, Chrysler personnel pulled the pack. There was some minor difficulties and two serious safety violations.

a. The pack was only partially removed from the hull and was held there while the mechanic reached between the front of the pack and the bulkhead to retrieve the filter.

b. When reinstalling the final drive shafts, the Chrysler test engineer used a procedure different from that in the manuals. He had the driver put the vehicle in drive and slowly let off on the brake while he pushed the shafts back into the transmission outputs with his hands. While doing this he was leaning into the sprocket and when the F.D. shaft seated, the vehicle lurched forward. When I asked him why he hadn't used the procedures in the manuals he said that he had never read "your" (the Army's) manuals and he had always done it the other way.

DRCPM-GCM-SM 2 May 1978
SUBJECT: Trip Report to Ft. Bliss Texas to Investigate Engine Problems

7. A power check was subsequently performed, the pack checked out O.K. and the test set performed satisfactorily. On Thursday P4 was taken for a confirmatory performance run. Top speed was 50 MPH and acceleration was 0-20 MPH in approximately 6 seconds.

8. A meeting was held Wednesday with LTC Sechtman and Chrysler representatives. LTC Sechtman stressed the importance of accurate manuals for OT II. I mentioned that, from what I had seen, Chrysler had a long way to go in a short time before their manuals would be satisfactory. Examples are the lack of adequate fuel system troubleshooting procedures and the dead end that was encountered in attempting to get P5 running.

9. On Thursday I had a discussion with Mr. Bob Wagner, Chrysler's Test Site Manager, on my impressions of the contractor test support. My comments were confined to the personnel I had observed working on the engine and included:

a. Lack of positive direction by the senior man present at any time and consequent debate between tech reps as to the best course of action.

b. Apparent lack of professionalism of the contractor tech reps as evidenced by disregard of basic safety procedures.

c. Unfamiliarity of tech reps with maintenance manuals and procedures given in the manuals.

d. The necessity for Chrysler personnel to "clean up their act" since they are viewed as the experts on the system, manuals, and maintenance by the military personnel at Ft. Bliss.

10. Several other comments and pieces of information were obtained while at Ft. Bliss.

a. A suggestion was made by Mr. Egan, AVCO, that on-site manual revision teams be considered to reduce the time between identification of a manual problem and the publication of the appropriate change.

b. The necessity for the manuals to be exhaustive in their troubleshooting procedures became obvious and was mentioned several times.

c. Test sets are not validated, that is, there has been no on-vehicle check of the appropriate component to insure that the set will properly diagnose a particular fault. Consequently confidence in the test sets is low. Chrysler-Huntsville personnel were reprogramming the fire control test set when I was there.

d. Mr. Egan, AVCO, stated that the Engine DS test set may not differentiate between a good and bad engine. He stated that, given an engine that is bad as determined by failure to pass the power check using the Engine Organizational Test set, the DS test set will tell you whether to replace the front or rear module, or both. Therefore, it cannot be used to check out a rebuilt engine.

e. The overflow return line from the rear to front tanks of P4 did not operate properly. During the power pack changeout, the front tanks were inadvertently pumped into the rear ones. Instead of returning the fuel to the front tanks, it seeped out around the sponson filler cap gaskets and dripped into the hull.

f. LTC Sechtman stated that he wanted to keep a residual training team at Ft. Bliss during OT II but that he could not get it funded. He may ask PMO to fund it.

PAUL M. ROOT
MAJ, OrdC

Appendix A-8

DRCPM-GCM-SM 5 July 1978

MEMORANDUM FOR RECORD:

SUBJECT: Trip Report to YPG

1. On 26-30 June I traveled to YPG to observe vehicle testing on PV1. Hydraulic system and fuel system tests were scheduled.

2. On Monday, 26 June, the hydraulic system return line filter clogged and there were no spares in the MTSP. Spares were ordered from Detroit and Ft. Bliss. Spares finally were located at Yuma Airport at 1700, 27 June. They had apparently been there since 0700 that day. Bendix installed a new circuit board in the ECU on 27 June.

3. 28 June hydraulic system tests were conducted on the dynamometer course. After one hour of running at 35-40 MPH and slewing the turret $\pm$ 45°, the hydraulic fluid had reached 254° above the specified 250° limit. The test was terminated. The right cooling fan apparently never came on and, as a consequence, there was little airflow over the hydraulic cooler. The test is scheduled to be repeated when the right fan can be locked on.

4. 29 and 30 June were spent in instrumenting the vehicle for fuel system tests. New fuel pumps, Validation FWS and new HNB were installed. Pressure and temperature sensors were installed throughout the fuel system. Instrumentation is continuing.

5. Random observations on the operation at YPG:

a. It is basically a one-shift operation, 0700-1530. They start closing up around 1500. I was told that if they were running mileage, they would work later. In a hot weather test center, they should regularly run until 1800.

b. There appeared to be no sense of urgency, although there were complaints about being behind schedule.

c. There didn't appear to be much advance planning or work-around planning. When the vehicle was awaiting a hydraulic filter, little else was planned. There didn't appear to be a lot of coordination with the instrumentation lab: On Thursday afternoon the test engineer was not sure if he could get the necessary support to install telemetry on the vehicle on Friday.

d. There is no single individual dedicated to running the XM1 tests. Mr. Twomey has other tests to conduct as well and must necessarily divide his time.

DRCPM-GCM-SM 5 July 1978
SUBJECT: Trip Report to YPG

e. There were unconfirmed reports that the GI crews and mechanics had not been trained on the vehicle.

f. Spare parts support is bad. The MTSP is inadequate and has not been updated based on the Ft. Bliss experience.

g. An NCO reported to me that tech reps were alibiing problems as "being normal" rather than investigating and solving them. Examples were roadwheel seal leaks, an oil leak at engine/transmission interface, and a reported engine surge.

6. Recommendations:

a. Two-shift operation be instituted if necessary to take advantage of hot weather during the day.

b. Instrumentation and maintenance be conducted second shift to accelerate the test program.

c. A single person be given authority to run and direct the test with no other duties or test programs.

d. Spare part support be upgraded.

PAUL M. ROOT
MAJ, OrdC

Appendix A-9

XMI

MAJ ROOT

DEC 79

AGT 1500

TURBINE ENGINE

FOR

XM1

TANK

OUTLINE

ENGINE DESCRIPTION

TEST PROGRAM

MAINTENANCE POLICY

AGT 1500 ENGINE
DESIGNED SPECIFICALLY
FOR U.S. ARMY TANK APPLICATIONS

- INSTALLATION FEATURES
  - HARD MOUNT TO TRANSMISSION
  - 3000 RPM OUTPUT SPEED
  - INLET/EXHAUST CONFIGURATION
- OPERATIONAL FEATURES
  - "WET COMPARTMENT" FOR FORDING
  - MULTI-FUEL CAPABILITY
- MAINTENANCE FEATURES
  - SINGLE CAN COMBUSTOR
  - ALL ACCESSORIES REPLACEABLE IN VEHICLE
  - MODULAR DESIGN

XMI

AGT 1500 ENGINE CONFIGURATION

DESCRIPTIVE CHARACTERISTICS

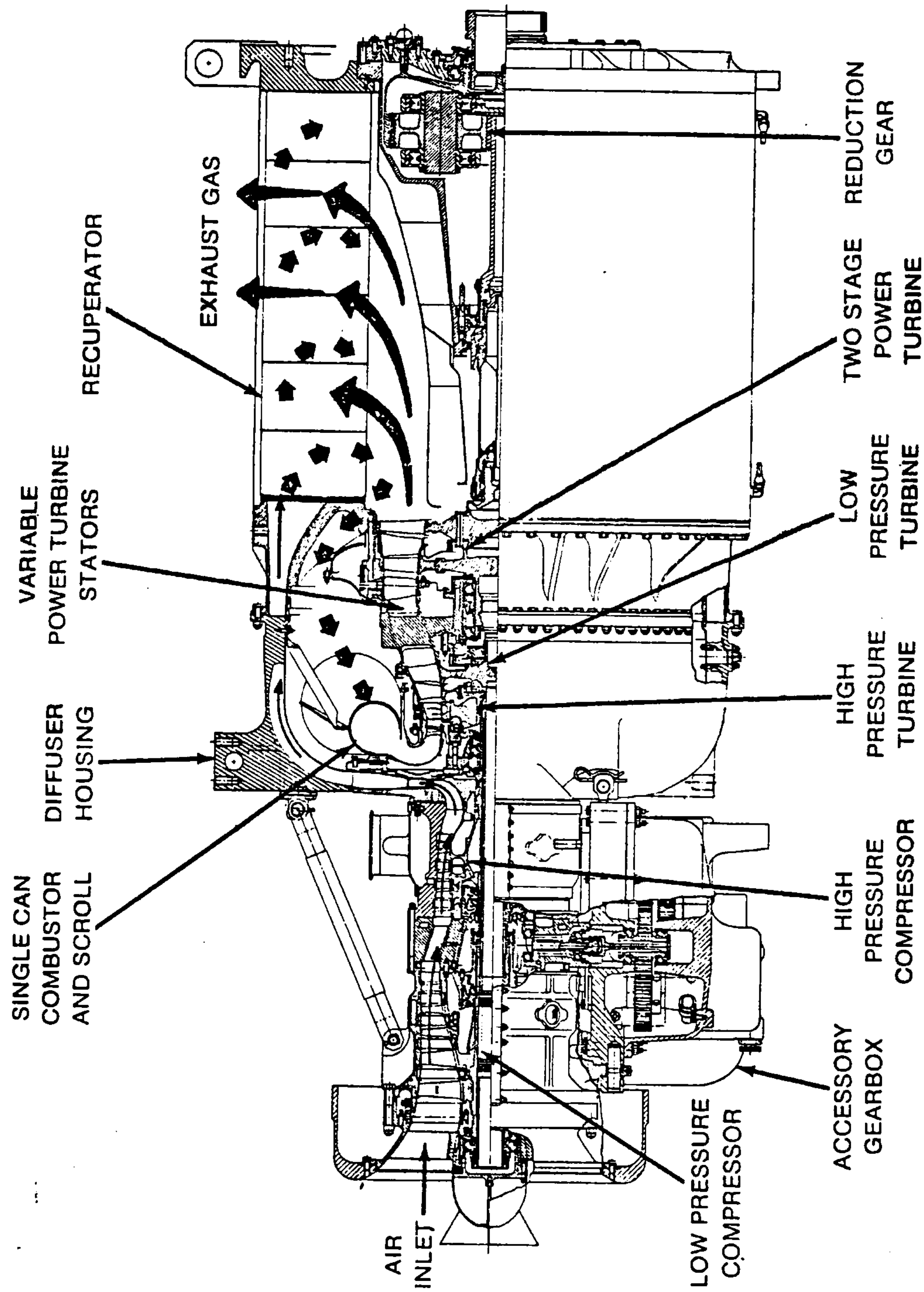
- 1500 HORSEPOWER NET OUTPUT
- WEIGHT 2500 POUNDS
- FREE POWER TURBINE
- AXIAL INLET
- VERTICAL EXHAUST
- REAR DRIVE
- LENGTH 63.5 IN. — WIDTH 40 IN. — HEIGHT 28 IN.

XMI

AGT 1500 ENGINE

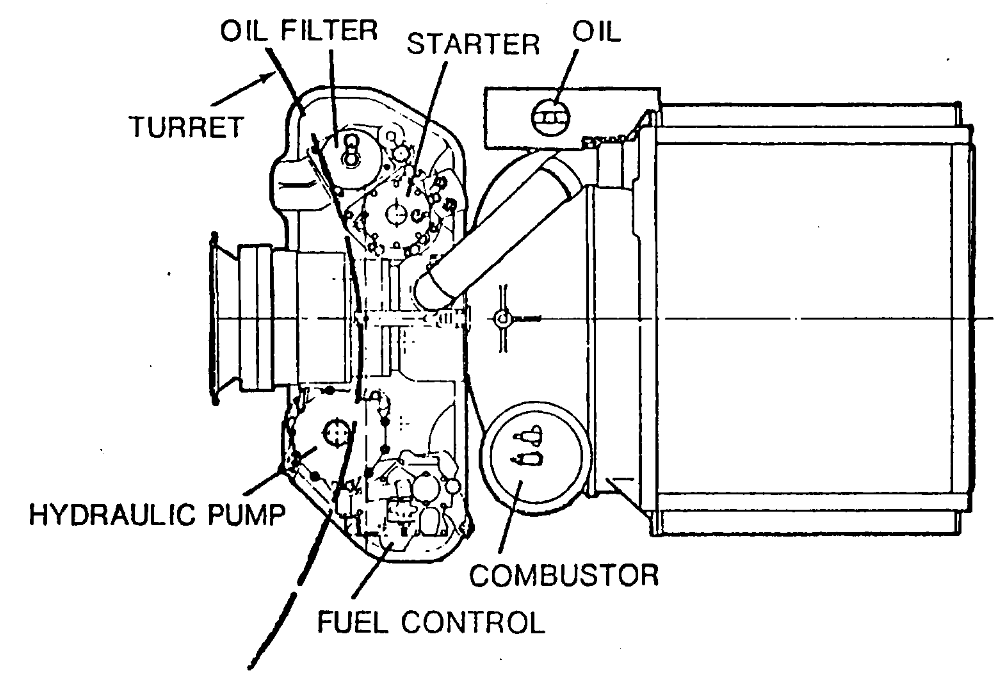
TECHNICAL DESCRIPTION

- TWO SPOOL GAS PRODUCER
- FREE POWER TURBINE
- EXHAUST GAS RECUPERATOR
- SINGLE CAN COMBUSTOR
- 12 LBS PER SECOND AIRFLOW
- 2180°F TURBINE INLET TEMPERATURE
- VARIABLE INLET GUIDE VANES
- VARIABLE POWER TURBINE STATORS
- ELECTRONIC FUEL CONTROL


SINGLE CAN COMBUSTOR AND SCROLL
DIFFUSER HOUSING
VARIABLE POWER TURBINE STATORS
RECUPERATOR
EXHAUST GAS
AIR INLET
LOW PRESSURE COMPRESSOR
ACCESSORY GEARBOX
HIGH PRESSURE COMPRESSOR
HIGH PRESSURE TURBINE
LOW PRESSURE TURBINE
TWO STAGE POWER TURBINE
REDUCTION GEAR

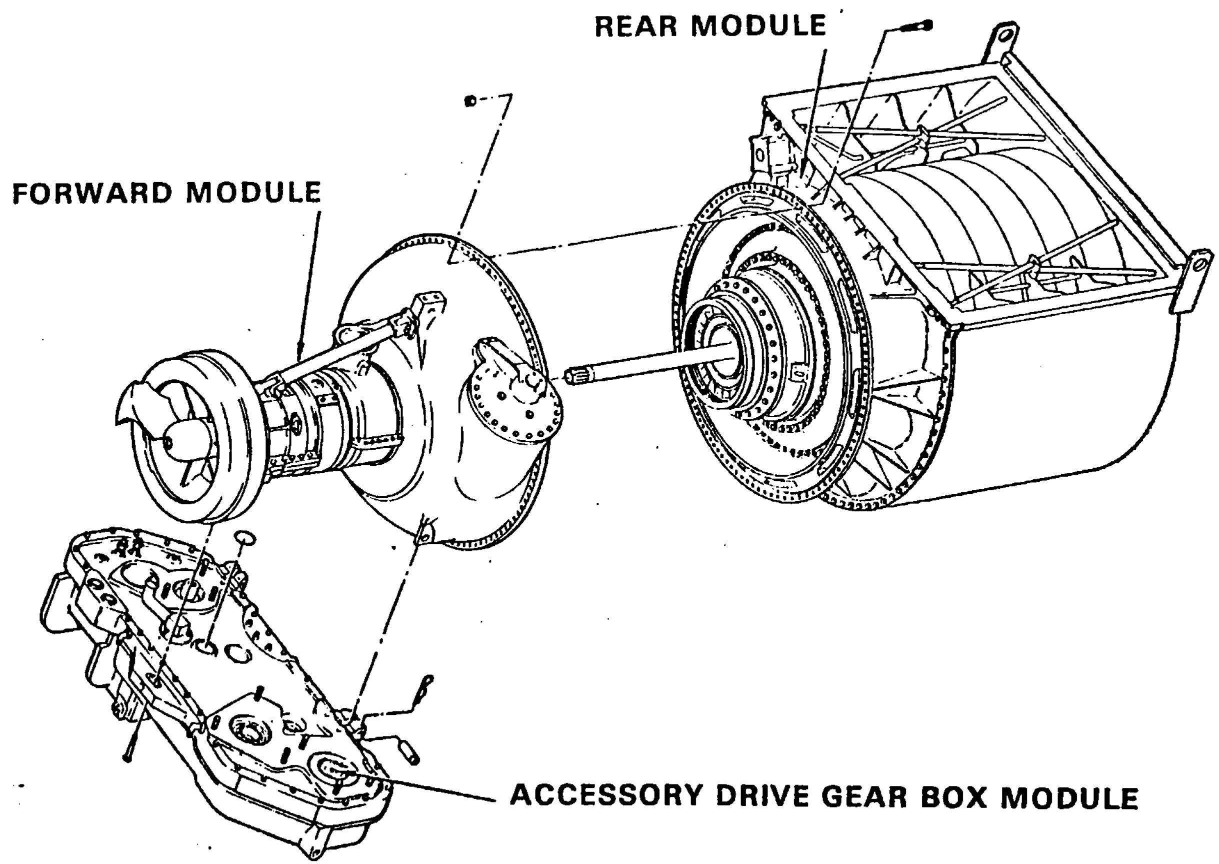
DESIGNED FOR MAINTAINABILITY

TOP ACCESSABILITY

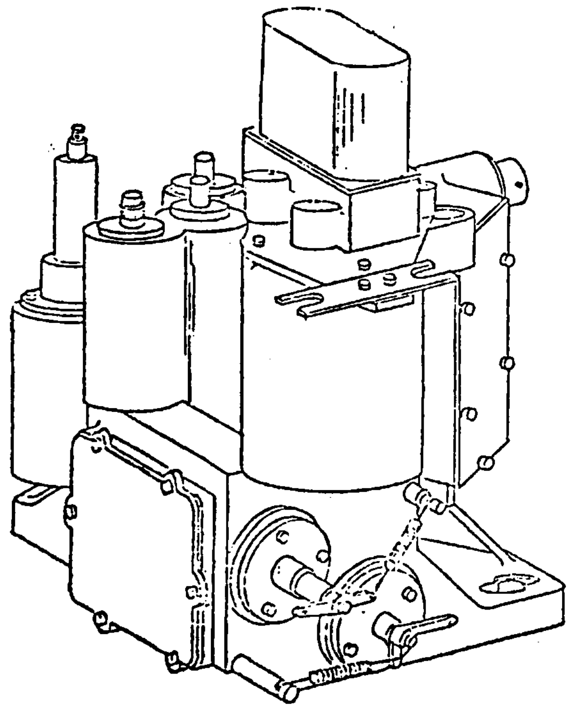


XMI

AGT 1500 MODULAR CONSTRUCTION

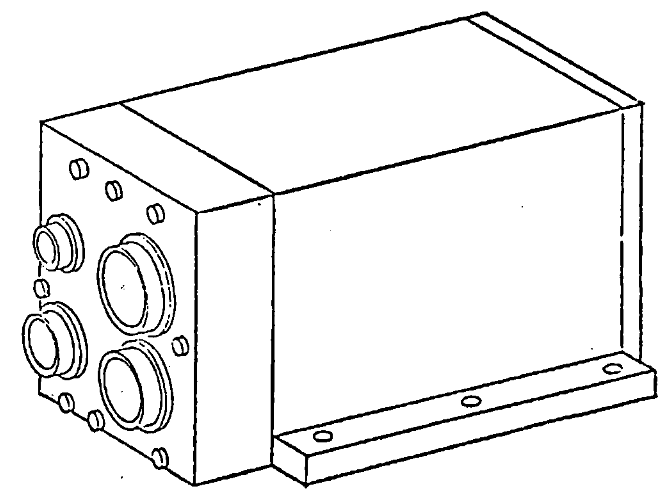


ELECTRONIC FUEL CONTROL SYSTEM COMPONENTS

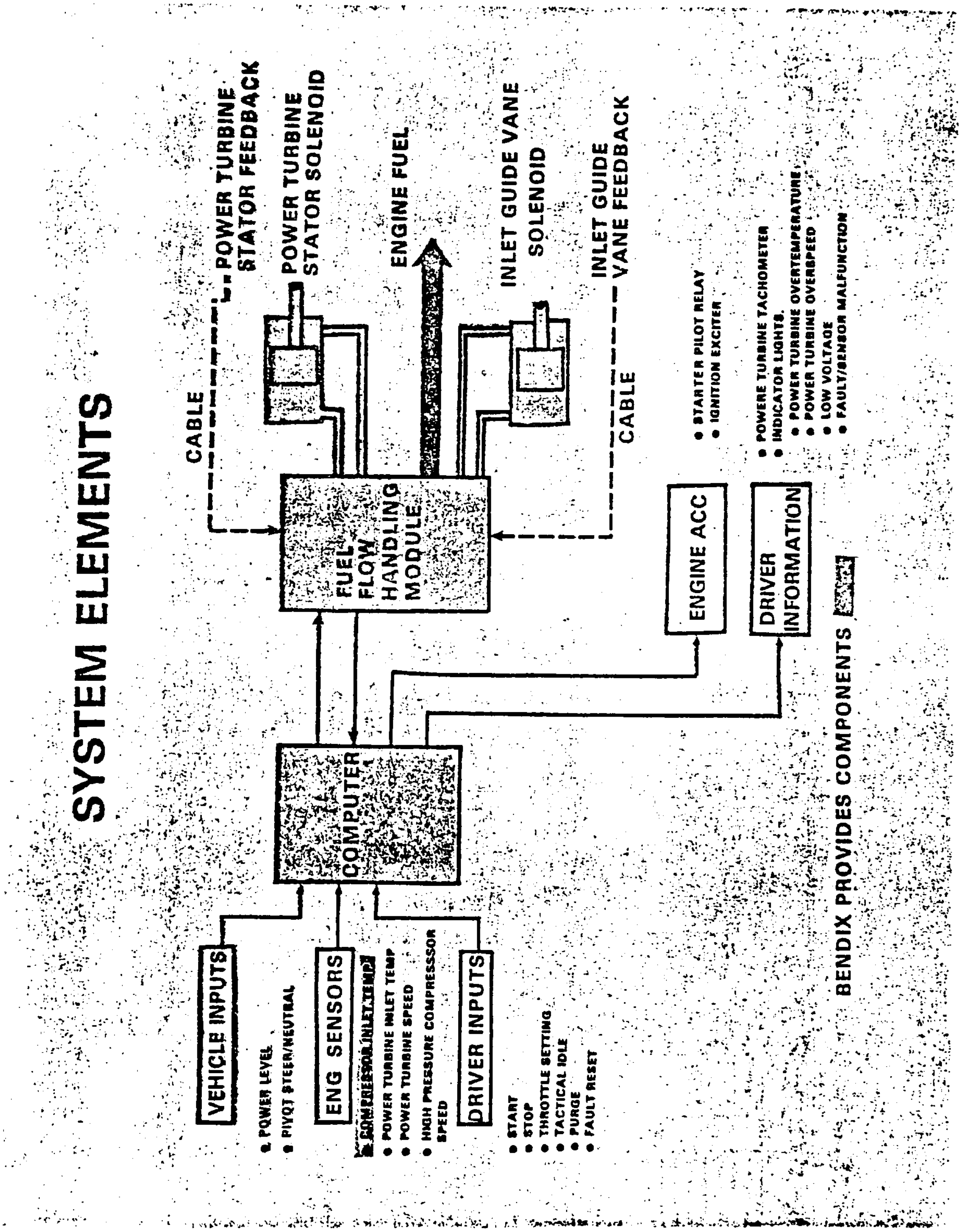


FLOW HANDLING MODULE

TI SENSOR



COMPUTER


SYSTEM ELEMENTS
VEHICLE INPUTS
• POWER LEVEL
• PIVOT STEER/NEUTRAL
ENG SENSORS
• COMPRESSOR INLET TEMP
• POWER TURBINE INLET TEMP
• POWER TURBINE SPEED
• HIGH PRESSURE COMPRESSOR SPEED
DRIVER INPUTS
• START
• STOP
• THROTTLE SETTING
• TACTICAL IDLE
• PURGE
• FAULT RESET
COMPUTER
FUEL FLOW HANDLING MODULE
CABLE
POWER TURBINE STATOR FEEDBACK
POWER TURBINE STATOR SOLENOID
ENGINE FUEL
INLET GUIDE VANE SOLENOID
INLET GUIDE VANE FEEDBACK
CABLE
ENGINE ACC
• STARTER PILOT RELAY
• IGNITION EXCITER
DRIVER INFORMATION
• POWERE TURBINE TACHOMETER
• INDICATOR LIGHTS.
• POWER TURBINE OVERTEMPERATURE
• POWER TURBINE OVERSPEED
• LOW VOLTAGE
• FAULT/SENSOR MALFUNCTION
BENDIX PROVIDES COMPONENTS

XMI

AGT 1500 ENGINE

TURBINE ADVANTAGES

BEST ACCELERATION

MORE HP AVAILABLE AT SPROCKET

SUPERIOR LOW SPEED TORQUE

NO SMOKE

EASY COLD START

INCREASED DURABILITY POTENTIAL

QUIET ENGINE

COOLING CAPACITY

MAINTAINABILITY

OPERATION IN DUST

TURBINE DISADVANTAGES

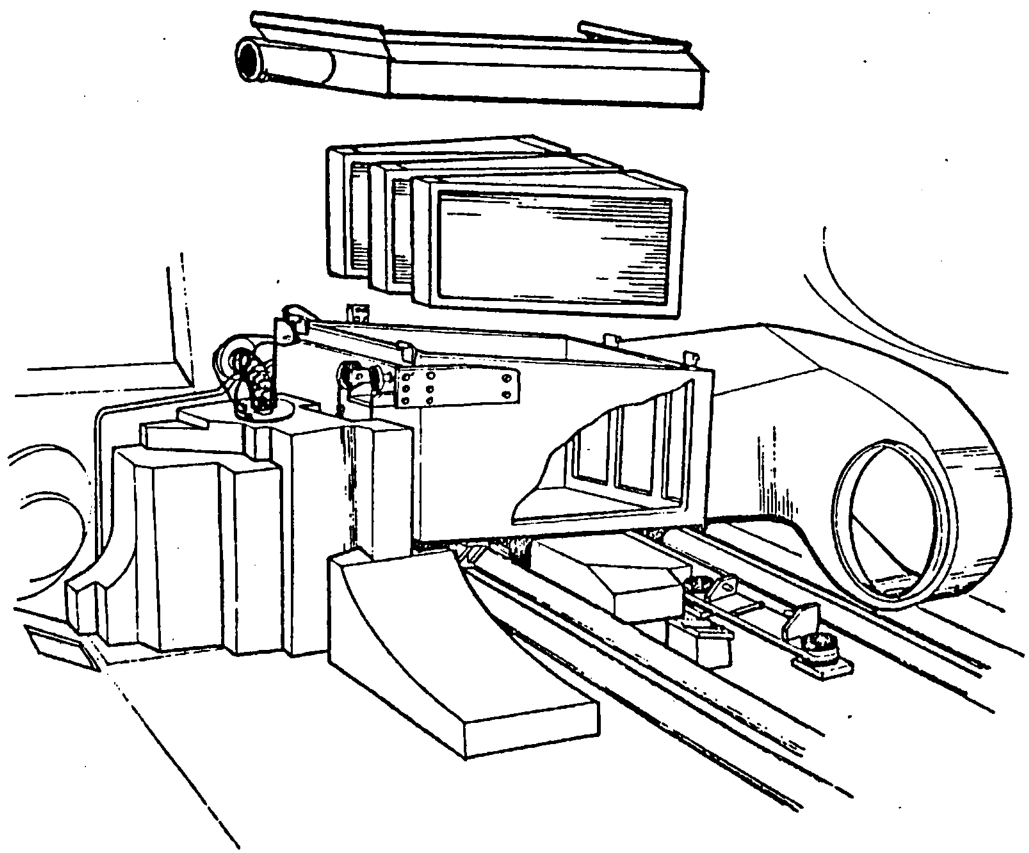
HIGHER FUEL CONSUMPTION

HIGHER ACQUISITION COST

EXHAUST SNORKEL REQUIRED
FOR DEEP FORDING

LONGER ENGINE STARTING TIME

AIR INDUCTION SYSTEM



XM1 TRANSMISSION CHARACTERISTICS

TYPE	HYDROKINETIC-FULLY AUTOMATIC 4 SPEED FORWARD 2 SPEED REVERSE
MODEL	X1100-3B
MAXIMUM GROSS INPUT POWER	1500 HP AT 3000 RPM
MAXIMUM NET INPUT TORQUE	3250 LBS. FT
DRIVE RATIOS	
• FIRST	5.9:1
• SECOND	3.0:1
• THIRD	1.9:1
• FOURTH	1.3:1
• REVERSE-1	8.3:1
• REVERSE-2	2.3:1
OPERATING INPUT SPEED RANGE	850 RPM TO 3200 RPM
STEERING	HYDROSTATICALLY-CONTROLLED DIFFERENTIAL PIVOT STEER IN NEUTRAL
BRAKES	MULTIPLE WET PLATE, SERVICE AND PARKING

DRY WEIGHT (INCLUDING OIL FILTER & MANIFOLD)-4340 LBS

XMI

AUTOMOTIVE PERFORMANCE

AGT 1500 ENGINE/X1100 TRANSMISSION

ACCELERATION 0-20 MPH	6.2 SEC
TOP SPEED (GOVERNED)	45 MPH
10% SLOPE SPEED	24 MPH
60% SLOPE SPEED	5 MPH
CROSS COUNTRY SPEED	GREATER THAN 30 MPH
FUEL CONSUMPTION — SECONDARY ROAD, 25 MPH	.55 MILES/GALLON
— PAVED ROAD 25 MPH	.63 MILES/GALLON
FUEL CONSUMPTION — PAVED, 32 MPH	.71 MILES/GALLON

TEST PROGRAM

XMI

XMI

AGT-1500 TURBINE ENGINE

NEW ENGINES	LABORATORY HOURS	TOTAL HOURS	VEHICLE MILES
	PRIOR TO VALIDATION PHASE		
24	5,800	6,850	6,400
	DURING VALIDATION PHASE		
8	2,400	4,070	16,700
	FSED		
20	7,900	19,600	75,000
	RELIABILITY IMPROVEMENT PROGRAM		
1	2,400	4000	16,000
	TOTAL PRIOR TO INITIAL PRODUCTION		
53	18,500	34,520	114,100

XMI

ENGINE LABORATORY TESTING

FSED

TYPE	HOURS	PURPOSE
GENERAL DEVELOPMENT	1400	COMPLETE ENGINE DEVELOPMENT
FUEL MANAGEMENT SYSTEM	1800	DEVELOP ELECTRONIC FUEL MANAGEMENT SYSTEM
DF2 TESTING	1500	DEVELOP COMBUSTOR SYSTEM
PRELIMINARY LOW CYCLE FATIGUE	250	DETERMINE LCF LIFE OF ENGINE
ABUSIVE (ALTITUDE, ATTITUDE, HOT, COLD)	250	OPERATION UNDER EXTREME CONDITIONS
LOW CYCLE FATIGUE	100	LCF DEMONSTRATION
DURABILITY (3-400 HR NATO TESTS)	1400	DURABILITY DEMONSTRATION
MISSION PROFILE (3-6000 MILE TESTS)	1200	DURABILITY DEMONSTRATION
TOTAL	7900	

XMI

ENGINE LABORATORY TESTING

RELIABILITY IMPROVEMENT PROGRAM

TYPE	HOURS	PURPOSE
2-1000 HR TESTS	1000 EACH	IDENTIFY DURABILITY LIMITERS
• 400 HR ENDURANCE		
• 600 HR MISSION PROFILE		DEMONSTRATE DESIGN MATURITY

XMI

LOW CYCLE FATIGUE (LCF) TEST

TYPE: DEVELOPMENT

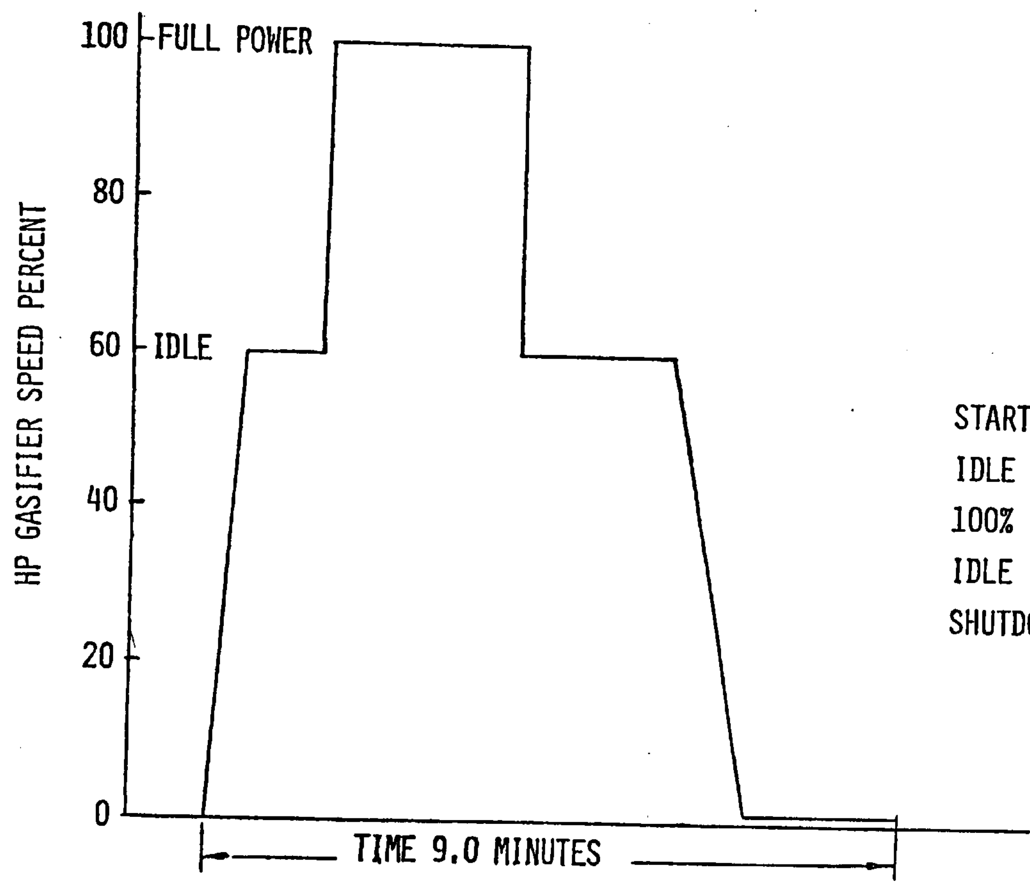
PURPOSE: TO STRESS LCF-SENSITIVE COMPONENTS

- COMPRESSOR BLADES
- COMPRESSOR DISCS
- TURBINE WHEELS
- TURBINE BLADES

DURATION: AS DETERMINED

XMI

LCF CYCLE



START	.5
IDLE	1.0
100% POWER	2.5
IDLE	2.0
SHUTDOWN	3.0

NATO CYCLE TESTING

TYPE: DURABILITY- STEADY STATE
HIGH POWER
HIGH TEMPERATURE

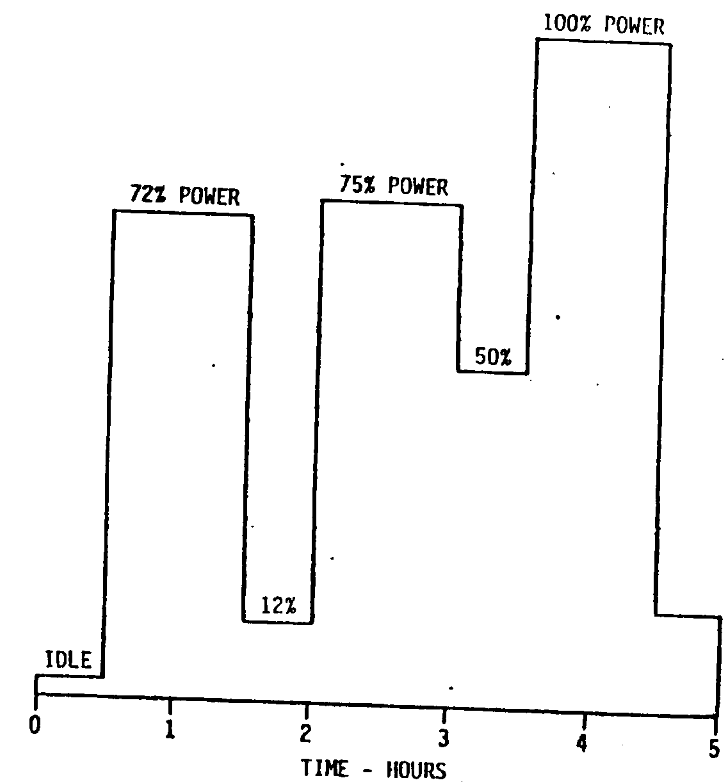
PURPOSE: DEMONSTRATE DURABILITY UNDER STEADY-STATE OPERATING CONDITIONS

- STRESSES THOSE COMPONENTS SENSITIVE TO STRESS-RUPTURE FAILURE
  - TURBINE WHEELS
  - TURBINE BLADES
- STRESSES THOSE COMPONENTS SENSITIVE TO MAXIMUM TEMPERATURE
  - COMBUSTOR SYSTEM
  - TURBINE NOZZLES
  - TURBINE BLADES

DURATION: 400 HOURS

400 HOUR DURABILITY TEST CYCLE

- 80 5 HOUR CYCLES CONSISTING OF:



- 40 CYCLES RUN AT 87°F
- 40 CYCLES RUN AT 59°F
- FUEL VVF800 DF-2
  OIL MIL-L-23699
- ENGINE CALIBRATED AT 100 HOUR INTERVALS

XMI

MISSION PROFILE TESTING

TYPE: DURABILITY

PURPOSE: DEMONSTRATE DURABILITY UNDER TANK MISSION PROFILE CONDITIONS

DURATION: 6000 MILES (350 HOURS) - WITH TRANSMISSION

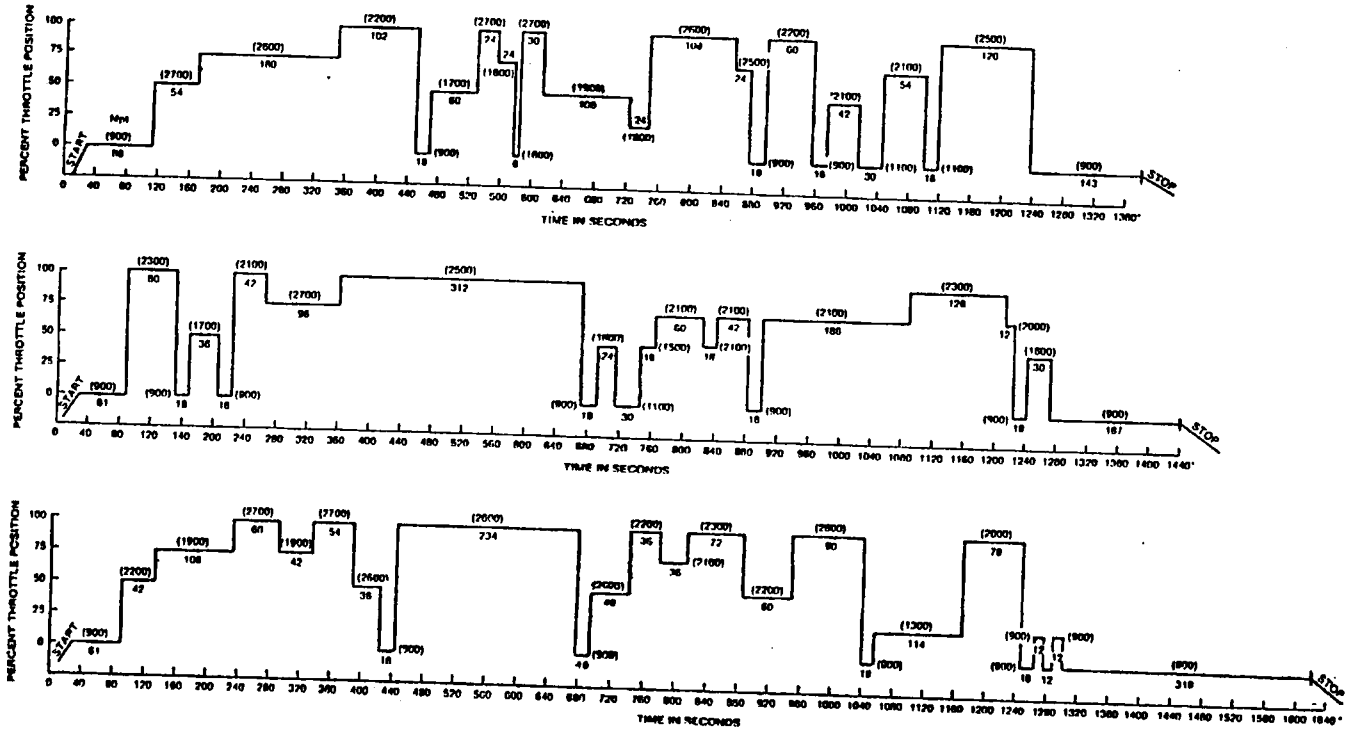
600 HOURS (9960 MILES) - ENGINE ALONE

XMI

600-HOUR MISSION PROFILE TEST

(NUMBERS IN PARENTHESES ARE NH SPEEDS)

*3 MINUTE WAIT BEFORE NEXT START



XMI

1000 HOUR TEST

TYPE - DURABILITY -

- 400 HOUR NATO CYCLE TEST FOLLOWED BY 600 HOUR MISSION PROFILE TEST

PURPOSE -

- DEMONSTRATE DESIGN MATURITY
- IDENTIFY DURABILITY LIMITERS
- SEVERE OVERTEST OF ENGINE (17,000 - 21,000 MILE EQUIVALENT)

DURATION - 1000 HOURS

XMI

VEHICLE TESTING

CURRENT STATUS

TEST	TYPE	LOCATIONS	PURPOSE	MILES
DEVELOPMENT	ENGINEERING	ABERDEEN PG YUMA PG FORT KNOX EGLIN AFB	ENGINEERING EVALUATION OF TANK & SUBSYSTEMS	26,671
OPERATIONAL	USER	FORT BLISS	TO TEST OPERATIONAL EFFECTIVENESS OF TANK	19,097
EXTENDED DURABILITY	AUTOMOTIVE	FORT KNOX	DEMONSTRATE AUTOMOTIVE RELIABILITY & DURABILITY IMPROVEMENTS	15,582
CONTRACTOR	ENGINEERING & DURABILITY	CHELSEA PG ABERDEEN PG FORT KNOX WHITE SANDS FORT BLISS	CONTRACTOR DEVELOPMENT & AUTOMOTIVE DURABILITY	29,110
			TOTAL	90,460

XMI

FUTURE TESTING

- 2 1000 HOUR TESTS - PRODUCTION ENGINES
  - CONFIRM PRODUCTION PROCESS
- DT/OT III AND CONTRACTOR VEHICLE TESTING - 100,000 MILES
  - ENGINEERING TESTS
  - OPERATIONAL SUITABILITY
  - RELIABILITY & DURABILITY
  - LOGISTIC SUPPORTABILITY

XMI

ENGINE

OVERHAUL/DESIGN LIFE

OVERHAUL INTERVAL -	TANK - 6000 MILES ENGINE - 6000 MILES
DESIGN GOAL -	ENGINE - .87 PROBABILITY OF 4000 MILES WITHOUT A DURABILITY FAILURE

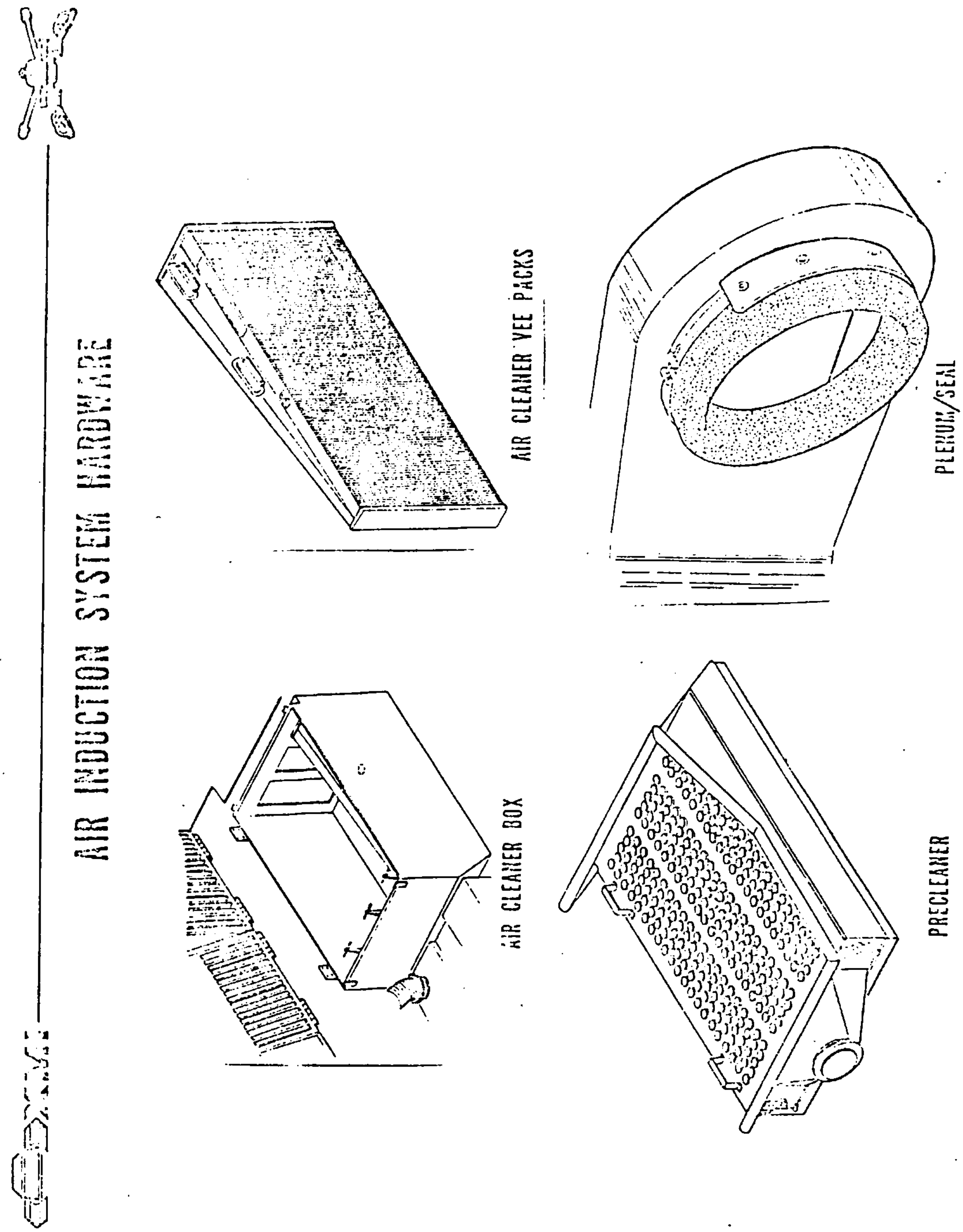
XMI

MAINTENANCE POLICY

CREW	- MAINTAIN FLUID LEVELS - CLEAN & INSPECT
ORGANIZATIONAL	- REPLACE EXTERNAL COMPONENTS - REPLACE ACCESSORIES - CLEAN & INSPECT
DIRECT SUPPORT	- REPLACE MODULES - REPLACE ENGINE - REPLACE EXTERNAL COMPONENTS
GENERAL SUPPORT/DEPOT	- REPLACE INTERNAL COMPONENTS OVERHAUL MODULES/ENGINE

APPENDIX B

Appendix B-1


AIR INDUCTION SYSTEM HARDWARE
AIR CLEANER VEE PACKS
PLENUM/SEAL
AIR CLEANER BOX
PRECLEANER

Appendix B-2

11ay Rome

DRCPM-GCM-SM 25 July 1978

MEMORANDUM FOR RECORD:

SUBJECT: Trip Report to AVCO Lycoming

1. On 6 July 1978 I visited AVCO Lycoming to inspect damaged engines #38 and 42.

2. Engine #38 was returned from Ft. Bliss due to compressor surging. Inspection of the disassembled engine revealed severe sand erosion to the 1st stage HP compressor and lesser damage to the remainder of the LP & HP compressors. The 1st stage HP compressor blades were missing the outer 25% and the leading and trailing edges were bent and torn. The remaining HP compressors had ripped and torn blades. All stator rows were damaged.

3. The LP compressor showed slight erosion to the 1st stage blades. The 3rd and 4th stages had slightly dished leading edges and the trailing edge of the fifth stage had FOD from the HP compressor. The trailing edges of last stage of LP stators were badly damaged from the HP compressor.

4. Sand had passed through the recuperator and had been melted in the combustor. It solidifies as "glass" (really a crumbly, porous ceramic) on the splash rings of the combustor and the scroll. Half of the blades of the HP turbine nozzle had cracks in their leading edges and some had glass on the rear surfaces of the blades. The trailing edge of a quarter of the blades had burned away. Half of the blades of the HP turbine had cracks and burn-through marks on the leading edge. The LP nozzle had small burn-through holes at the leading edge of nearly all the blades where the blades meet the outer support ring.

5. Sand erosion damage is apparently worst on the first stage HP compressor for this engine. This is probably due to the fact that the HP compressor rotates opposite to the LP compressor and at different speeds. The engine airflow diameter also narrows at this point. Due to centrifugal force, the sand is concentrated at the outside of the airflow path and the large difference in relative velocities between the sand and air leaving the LP compressor and entering the counter-rotating HP compressor make for very rapid erosion of the 1st stage HP compressor.

6. Engine #42 failed to start at the Tank Plant while installed in P10 prior to government acceptance. Inspection at AVCO revealed extensive damage to the HP & LP turbine stages. AVCO stated that the damage was

DRCPM-GCM-SM 25 July 1978
SUBJECT: Trip Report to AVCO Lycoming

caused by a portion of the lip of the combustor dome which surrounds the injector (see Inclosure 1) breaking off. This hit the HP turbine, breaking off the top half of one blade. The HP turbine had evidence of severe tip rubs caused by the inner support ring and shroud cylinder breaking away from the HP nozzle. Half the blades of the HP nozzle had evidence of overheating (or FOD from small particles) on their leading edges. Two blades were missing pieces from their trailing edges. Half the blades of the LP nozzle were burned through on their leading edge. The blades had broken loose from their inner mounting support on a braze line and the inner seal surface was damaged. The LP turbine wheel had carbon deposits on its bolt circle and tip rubs on the trailing third of the blades. There was also considerable flaking of the thermal barrier coating of the combustor liner.

7. The engine has been rebuilt and is in test at AVCO. It is due for delivery by 14 July.

8. Modifications are being made to combustor domes to avoid recurrence of this problem (it first occurred in engine #28).

9. Other information from AVCO:

a. Bill Boss, a fuel systems consultant from Chrysler was at AVCO for fuel systems test. He stated that DF2 fuel would vaporize at 11-12 PSI absolute (-3PSI G) and at Ft. Bliss, the atmospheric pressure is approximately 12.7 PSI absolute. Therefore, with only slight negative pressure in the fuel system, vapor could form at the high ambient temperatures encountered.

b. The fuel encounters a 30°F temperature rise passing through the fuel control at full throttle and 60°F at idle due to the bypass and recirculation of fuel.

c. AVCO has postponed possible incorporation of fixed IGV's in the engine due to surge problems and the failure of engine #39. This will have a DTC impact.

d. AVCO is pursuing their redesign of the 1st stage HP compressor blade to give it a greater surge margin.

e. AVCO is studying modification of the IGV schedule to provide a greater surge margin and avoid a repeat of the failure of engine #39.

1 Incl
as

PAUL M. ROOT
MAJOR, ORD

174

Appendix B-3

good fact sheet
Keep on top of this.
B

DRCPM-GCM-SM

FACT SHEET

Automotive Branch
MAJ Root/31231
7 August 1978

SUBJECT: Chrysler Attempts to Solve Air Cleaning Problems

Project Manager, XM1 Tank System

PURPOSE: To detail the efforts Chrysler plans to take to eliminate air cleaning system problems.

FACTS:
1. On 2 August 1978 Chrysler conducted meetings concerned with solving the air cleaner system problems which have been causing engine failures due to dust ingestion. The problems can be categorized as:

   a. Air plenum seal leaks and failures.

   b. Failure to seal V-Pack/air cleaner box interface.

   c. Loss of efficiency of scavenge blower.

2. The morning meeting concerned the plenum and seal problem. Representatives from several seal manufacturers were present (TAB A). Chrysler decided to extend the lip of the plenum box from 1" to 1.5" or 1.75" by moving the rear wall of the plenum forward. A bead has been added to the lip. A kit will be designed and the modification will be applied to the OT vehicle plenums during the modification period.

3. Representatives of three different companies presented proposals to manufacture a more suitable, reliable plenum seal. Lead time on producing the required molds is the pacing item, and the earliest a new seal will be available from any of the companies is 4-6 weeks. Each of the separate designs will be evaluated. A band clamp was decided upon as the best means of fastening the seal to the plenum. Cables have been shown to loosen over a period of time. Because of the lead time involved in producing new seals, it appears that the modified plenum will be used with the present seal, at least for a short period.

4. An afternoon meeting was held with Donaldson representatives concerning the air cleaner system. Donaldson stated that during Validation they had produced the V-Packs, seals and air cleaner box. In FSED they produce the V-Packs only, and bond a Chrysler supplied seal to the end of the V-Pack. Chrysler manufactures the air cleaner box.

surprise.

DRCPM-GCM-SM 7 August 1978
SUBJECT: Chrysler Attempts to Solve Air Cleaning Problems

5. Donaldson agreed to the following:

a. Redesign the V-Packs within two weeks to include 1/4" shorter length, new seals, (compressor limiters,) and more rugged outer surfaces (expanded metal vs wire screen). Chrysler will design a new clamp and inspect the squareness of the air boxes and the parallelism of the ends of the boxes.

b. Supply a team to check the efficiency of the scavenge blower system and recommend possible improvements. It was generally agreed that a constant speed scavenge blower system such as the more expensive hydraulically driven blower used in Validation, was much better than a variable speed scavenger blower as is now used (mechanically driven, blower speed depends on engine speed). Chrysler is investigating a higher speed, mechanically driven scavenger blower.

c. In return for this, Chrysler agreed to fund Donaldson to build two complete air cleaner systems (V-Pack, seals, air cleaner box) for delivery in four months. These would be fastened to a Chrysler supplied plenum and tested on FV2 and 3 at Ft. Bliss. Chrysler will then evaluate the system against the present one with improvements and choose the better, considering cost. Chrysler is funding Donaldson for approximately $50,000.

6. These modifications, when incorporated, should greatly reduce or eliminate engine failures caused by dust ingestion.

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as

E. W. TRAPP
Chief, Systems Engineering Division

Appendix B-4

INFORMATION PAPER

DRCPM-GCM-SM
7 September 1979

SUBJECT: Air Induction System

FACTS.
1. XM1 testing in the harsh environment of Ft. Bliss, Texas, revealed shortcomings in the air induction system. Problems occurred in the following areas:

a. The air cleaner box was not stiff enough and could deform under load. The dimensional tolerances were too large. These permitted the barrier filters (V-pacs) to be installed and the required airtight seal would not be made.

b. Seals on the barrier filters (V-pacs) were originally glued in place and exposed on the end of the filter. During V-pac installation and removal, they could be damaged, become unglued, and be rolled out of position. This allowed unfiltered air to enter the engine.

c. The plenum seal, which forms the airtight seal between the nose of the engine and the plenum ring was difficult to install and could work loose during operation.

2. The air induction system has been modified to overcome the above shortcomings.

a. The air cleaner box structure has been stiffened and dimensional control tightened. Combined with the modifications to the V-pac sealing method, described below, this results in a system where the V-pacs are positively sealed in place when installed. It is impossible to lock the V-pacs in position if they are installed improperly due to the locking handle.

b. The seals have been removed from the end of the V-pacs and recessed in the end plate of the air cleaner box. In this position they are protected from damage during V-pac installation and removal. The V-pacs have a V-shaped ridge in the metal end plate which mates with this seal. The V-pacs cannot be locked in place if the ridge is not properly seated in the seal.

DRCPM-GCM-SM
7 September 1979

SUBJECT: Air Induction System

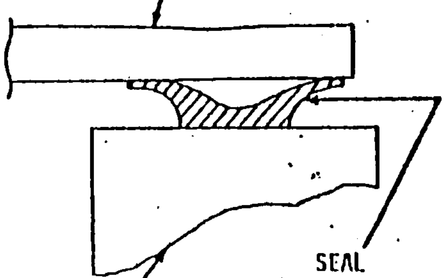
c. The plenum ring has been lengthened to give a larger surface for clamping the plenum seal. A bead has been added around the edge of the plenum ring to prevent the plenum seal, once installed and clamped down, from sliding off. The material of the plenum seal has been improved and a redundant seal added which is effective even if the outer seal is not properly clamped.

3. These modifications have resulted in an extremely reliable and effective air induction system. Since these modifications have been made, there have been no failures of the system during an extensive and rigorous test program.

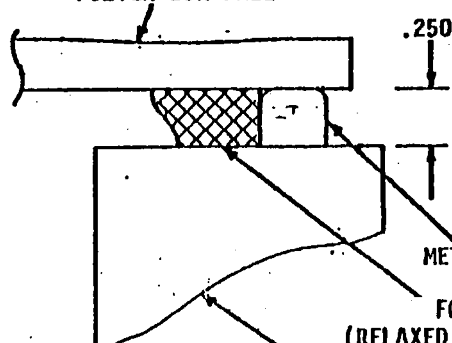
Appendix B-5

XMI

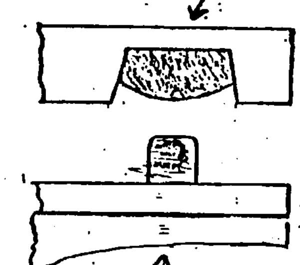
V - PAC BARRIER SEAL IMPROVEMENT



ORIGINAL SEAL CONFIGURATION



INTERIM SEAL CONFIGURATION



FINAL SEAL CONFIGURATION

Appendix B-6

DRCPM-GCM-SM 22 August 1979

MEMORANDUM FOR RECORD

SUBJECT: Trip Report to WSMR and Ft. Bliss

1. On 14-17 August 1979, I traveled to WSMR to inspect the test courses for the FV2 dust test and to Ft. Bliss to make initial coordination for the FV2 suspension test.

2. The test courses for FV2 will be adequate for a dust test provided it stops raining and the courses dry out. There were rain and floods the entire time I was there. People state that it will only take a week to dry out. However, this is the beginning of the rainy season at WSMR/Ft. Bliss, and rain can be expected from now on.

3. The two courses are both near the Small Missile Range (SMR) base camp.

a. A 4000 diameter circle near Parker Station. The tank may operate around the perimeter of the circle. The area is flat, with some scrub growth. A few passes with the tank will turn it over and if it dries out, there will be plenty of dust. This course can be closed in the event of missile firing.

b. A 4000-5000 meter course along trails from site Tracy to site Nan. This course is slightly rougher than the circle but should produce plenty of dust once it is broken out. This course is seldom closed for missile firings and will be used primarily when the circle is not available.

4. Chrysler has been provided office and storage space at SMR to use during the test. They have been provided a parts van (four wheel drive) which can proceed to either test site. They are procurring a four wheel drive vehicle for their own use. As of last Thursday, their office space was not set up although they were ready to begin vehicle testing.

5. Chrysler will operate one shift with three driver-mechanics from approximately 0700-1700 hours. Arrangements have been made with WSMR personnel to get access to the area prior to the normal workday.

DRCPM-GCM-SM 22 August 1979
SUBJECT: Trip Report to WSMR and Ft. Bliss

6. The environmental problems with the previously proposed test areas are real. New Mexico is very sticky concerning vehicle running in any area which has not undergone an archeological survey. I talked with Mr. Al Johnson, the environmental specialist and COL Geisel, the Facilities Engineer, and there is agreement that the current test areas are alright to use.

7. Chrysler is scheduled to run 250 miles per week on one shift. It will take aggressive leadership on the part of their site manager and FV2 test engineer to insure this schedule is met.

8. I made preliminary coordination with Ft. Bliss concerning the suspension test to be run in Area 6D in early October. POC is MAJ Paul Piper, Directorate of Plans and Training, AV 978-3631/3918. He foresees no problems with scheduling the test area or necessary support. He had not received an official copy of our coordinating TWX and will get it retransmitted this week.

PAUL M. ROOT
Major OrdC
Automotive Branch

Appendix B-7

DRCPM-GCM-SM 18 September 1979

MEMORANDUM FOR RECORD

SUBJECT: Report on Trip to Ft. Bliss and White Sands Missile Range

1. On 10 thru 13 September 1979, I traveled to White Sands, New Mexico, and Ft. Bliss, Texas, for the purpose of observing FV2 air cleaner testing and doing preliminary planning for the track test.

2. The FV2 test is running well. On 10 September, 106 km were run; on 11 September, 134 km. On Wednesday, 12 September, no mileage was accumulated because the range was closed where the test tracks are. About half of the mileage is being accumulated on Parker Site which is the 4000 ft circle. The dust is very deep there and very fine. The remainder is being accumulated on a tank trail that runs north from Small Missile Range approximately 13 km. The dust is not as heavy here but is adequate. The alternate road which goes up towards Rattlesnake Mountain is used but you cannot sustain as high a speed on it. Parker Site is the preferred site.

3. Comments on the test:

a. The mechanics for FV2 need a complete set of tools as soon as possible. They do not have such basic things as ratchets and the metric sockets which they need. There is only one set of tools available and it has to be shuttled back and forth between PV1 and FV2. This causes loss of time and some inefficiencies. The Chrysler test engineer states that the equipment is on order but is not there yet. The tools should be expedited. The support package should be reviewed to insure its adequacy for the air cleaner test and also the upcoming track test. V-packs, filter, both oil and fuel, and suspension parts are likely to be used at a high rate.

b. The Chrysler test plan calls for changing precleaner, scavenge blower and maybe cooling fans each 250 miles. This will result in excessive delays in the test program and should not be done. I propose that all changes be made after the track test is completed in October. Until that time we should accumulate mileage as quickly as possible. This needs to be emphasized to Chrysler. (Chrysler - Bob Hall has agreed to this.)

DRCPM-GCM-SM 18 September 1979
SUBJECT: Report on Trip to Ft. Bliss and White Sands Missile Range

c. The Chrysler organization is still a little ragged. The mechanics are good; willing to what is needed, but they need the guidance of a test engineer. Bob Benson, the latest test engineer arrived on Wednesday. He is the third test engineer on site since the vehicle was rebuilt. I hope he'll last. Chrysler needs to plan for contingencies and look ahead which they don't seem to be doing very often. An example of this is the fact that they didn't have necessary filters in their shop van on site but had to return to White Sands main post to get one. The site manager states that he has not been there himself very long and is trying to get things together. This doesn't answer the question because the test has been scheduled for several months and previous site managers or test engineers should have taken care of this.

d. Chrysler must be asked to refine their test plan. Currently, AVCO wishes to take engine measurements every 10 hours of operation and when the V-packs clog. This requires going over to the tank trail at SMR and running there. If the tank had been running at Parker Site, this results in the delay of returning to SMR, making the calibration run, changing V-packs and then returning to the tank trail. AVCO does not need these measurements each time the V-packs clog and the elimination of some of this testing should be discussed immediately with Chrysler. I don't think Chrysler knows exactly what's going on.

e. PMO needs an update on all mileage run on FV2 to date, where it was run and when, so we can determine what is really allowable against the dust test.

f. With the intensive usage that FV2 is getting, frequent oil analysis should be performed on both the engine and transmission. This is available in El Paso and was used during OT II. This analysis was requested of Chrysler who checked with the home office and the home office did not seem particularly enthusiastic. We should follow up and insist on this. The analysis needs a quick turn-around to detect any possible problems.

g. On Tuesday, 11 September, we had a safety problem with the vehicle. There are no hydraulics in the turret and the gun had been welded in an upward position. It was welded by welding an end connector to the gun shield and then to the turret. After operation on the 10th, it was found that this had cracked. Welders were called and the end connector was rewelded. The sides of the gun shield were welded to the turret and a track block was wedged inside the turret between the top of the gun and the turret roof. This track block is on end so the track pins rest between the turret roof and the top of the gun. It is safety wired and tied in place with rope so that should all the welds break, the gun will still be held in an up position.

h. Replaceable pad track is losing its pads during sustained operation at high speeds on the tank trail. In one case this posed a safety hazard where a pad was thrown forward of the vehicle bounced on the road and the tank drove underneath it and the pad nearly hit the tank commander. This is perhaps another reason for staying away from replaceable pad track.

i. After operations on the 11th, when pulling into the motor pool, the engine was idling and then shut itself down. It's not known why this happened. After a few minutes it was restarted. During the restart procedure, the engine gas overtemperature light and low oil pressure lights came on but the engine did not shut down and started normally. As soon as it came up to speed, the lights went out and the engine has been operating fine ever since. AVCO is not concerned.

j. The clogged oil filter warning light came on both the 11th and again the 12th of September. The first time it was found to be a loose connection; the second time was unknown but probably was still a loose connection. This should be watched closely.

4. When this air cleaner test was set up, PMO was assured that the alternate site, which is the road which runs up towards Rattlesnake Mountain, would never be closed during missile firings. The day of 12 September was lost due to the entire range area north of Highway 70 being closed three times for the same firing. Each time the firing was postponed and finally never occurred. As a result, no mileage was accumulated that day. When Chrysler finally got back on site, only maintenance could be performed. We need to find an additional site which will be open when these ranges are closed. LT Richardson should take that action immediately. (Note: Subsequent checks reveal that the area is closed only for Patriot firings. Only two are scheduled in the next month and one maybe cancelled. We can live with this.)

5. Air Cleaner System: On 11 September, the V-pack air cleaner warning light came on. The vehicle had been operating at Parker Site, was driven back to the tank trail and a calibration run was made. Two additional runs were made on the tank trail for a total of 78 km after the light came on with little noticeable loss of power. Several items on the air cleaner system are worthy of note:

a. The V-packs new weigh approximately 39 to 40 pounds. When removed, the left and center V-packs weighed 58 pounds and the right V-pack weighed 67 pounds. After cleaning, the right V-pack weighed 41 pounds.

DRCPM-GCM-SM 18 September 1979
SUBJECT: Report on Trip to Ft. Bliss and White Sands Missile Range

b. The V-pack was cleaned with 100 psi air and the Chrysler cleaning wand. The wand is a long metal tube with a disc about the size of a fifty cent piece on it with a single small hole in it. It took over 1-1/4 hours to clean the V-pack and it is a very dirty job. Suggest we get Donaldson engineers there to observe and if possible to clean the V-packs themselves according to procedures. Maybe they can come up with a better idea. A better cleaning wand is also required.

c. The difficulty in cleaning the V-packs comes from the fact that the folds in the barrier material are tight. If the folds were more open, the dirt would be more exposed and be easier to get out.

d. I have dust samples from White Sands, from Area 6 at Ft. Bliss and from the V-packs which are available if people want them.

e. There is a stock of spare V-packs on hand at White Sands. Some were damaged in transit. George Psaros had inspected them and marked the bad ones. The bad ones are still on site. They should be removed from the stock so they aren't inadvertently used. There is also a problem with identification of good and bad ones and this should be double-checked immediately with Chrysler.

f. When the V-packs were removed, Chrysler used a small portable 115 volt vacuum cleaner to clean out the air cleaner box and plenum. It worked fairly well. They have another version, a backpack 115 volt vacuum cleaner on site which has not yet been tested. We need to check to see if a 24 volt version exists which could be plugged into the vehicle electric system.

g. The metal blocks in the bottom of the air cleaner box at the rear which serve to locate the narrow end of the V-packs and line them up square with the front face seem to be improperly constructed. The slots into which the narrow end of the V-packs rest are too wide and thus you cannot get perfect alignment of the V-pack on the front face. When the V-packs were changed, there was approximately 1/2 inch of extra space in the slot which could result in misalignment of the V-pack. The clamp has a roller only and has nothing to square up the V-pack to the front fact so a lateral movement is possible. It is very difficult to judge when the V-packs are square and no way to tell if the seal is properly made. The tolerances should be reduced to practically zero. Chrysler should be notified immediately of this situation.

DRCPM-GCM-SM 18 September 1979
SUBJECT: Report on Trip to Ft. Bliss and White Sands Missile Range

h. When the V-packs were removed, the seals on the air cleaner box looked good. There was very little dust in the plenum. The air cleaner system seems to be working satisfactorily at this point; however, the care required in cleaning the V-packs, as mentioned above and the time consumed, will probably result in some troops not doing it properly.

6. Driver's Instruments: The low fuel warning light came on during operation and when it does, it activates the master caution light. The low fuel warning light flickers as the fuel level drops below the level of the indicator but the master caution light latches on. When the driver looks from the master caution light to his instrument panel, if the low fuel warning light has gone off, he doesn't know what caused his caution light to come on. This should be a latching light. The BITE lights are too dim when bright sunlight shines into the driver's compartment. You cannot see which indicators are on.

7. Chrysler is indicating that PV1 will have a new TIS and GPS installed in it and will run 500 miles of cross country testing in a "shake, rattle and roll" test to determine the ruggedness to the system. Additionally, approximately 100 rounds of main gun ammunition will be fired. I feel that PV1 is not the best vehicle nor is White Sands the best site to do this test. PV1 has a very old validation engine in it and it may not last the entire test. One of the Fort Knox vehicles, which is going to run additional mileage anyway, would seem to be logical choice for this particular test.

8. FV2 Track Test: On 12 September, I met with CPT Dyson and we discussed preliminary plans for the track test of FV2 with CPT Hamilton of DPT at Ft. Bliss. CPT Dyson had done much coordination the previous day so there wasn't too much left to do. The following items resulted from those discussions:

a. SGT Paul's driver is a specialist Case. He is no longer at Ft. Bliss.

b. The soil conditions at Ft. Bliss now are quite dry. Will the test be valid if there has not been rain prior to the test and we don't have the wet sandy conditions which caused so many problems?

c. We have reserved Area 6C for the full month of October. We will cancel further use of it when we have completed our tests.

d. We have cancelled the M60 requirement because no one wants to have one there to run with the test.

e. CPT Dyson needs funds citation at Ft. Bliss. He is handling this.

DRCPM-GCM-SM 18 September 1979
SUBJECT: Report on Trip to Ft. Bliss and White Sands Missile Range

f. A UH1 was requested to provide aerial photographic coverage of the testing on 10 October; also on 2-3 October, in case problems occur on the 10th.

g. If VIP's are to be transported out to Area 6C by helicopter, this should be handled through the Visitor's Bureau by CPT Shiflett. Anyone flying in a helicopter needs to carry dogtags and the name, rank, social service number of all passengers need to be provided to Ft. Bliss ahead of time.

h. If a UHI is used for VIP's, suggest that it leave Ft. Bliss at 1200 from the helipad in front of the old XM1 field office. It must return prior to 1800, otherwise landing must occur at the air field.

i. Sedans should be layed on for VIP's by CPT Shiflett with the Visitor's Bureau.

j. Fuel and an M88 will be on call from the 3d CAV which will be operating at Dona Ana.

k. A HET will be provided by White Sands and it is planned to transport FV2 to the test site and back each day reducing the driving time required.

PAUL M. ROOT
Major, OD
Automotive Branch

Appendix B-8

DRCPM-GCM-SM 15 February 1977

MEMORANDUM FOR: LTC FEENEY

SUBJECT: Turbine Overspeed Protection and T7 Temperature Indication for the Turbine Engine

1. The MFR on AGT-1500 overspeed protection, dated 25 January 1977 (Incl 1), raised the question of an indicator to show if the engine power turbine has exceeded 130% of rated speed. There is currently no such indicator, but the possibility of reaching 130% of rated speed (3900 RPM) is very remote. Two independent speed sensors on the reduction gearbox will provide input to two separate electronic logic circuits in the fuel control system. The first governs speed to 3150 RPM by reducing fuel flow to the engine. If this system should fail, a backup system is activated, when the power turbine reaches 3240 RPM, which puts the engine on a deceleration fuel schedule. Therefore, both sensors and both protection circuits would have to be inoperative at the same time for engine overspeed to be a problem. Additionally, if electrical power is lost, the engine automatically shifts to a fuel schedule which gives an engine output power of 300 HP, corresponding to a power turbine speed well below 3000 RPM.

2. The power output turbine wheels are designed with a bursting strength of 160% of rated speed (4800 RPM). This condition should never be reached because the overspeed protection circuitry reacts quickly enough to prevent the output from reaching even 130% of rated speed even if the engine should be completely unloaded at full speed and power (i.e., complete transmission failure which removed all load from the engine).

3. The transmission has built-in protection (an automatic upshift sequence) to prevent it from back driving the engine to an overspeed condition. A transmission failure (high speed downshift) would be necessary for this to occur.

4. If the tank accelerates while descending a hill, the transmission will not overspeed due to its automatic upshift sequence. The vehicle would have to reach 58.5 MPH in order for the power turbine to reach 130% of its rated speed.

5. The question of the meaning of the "T7" temperature as used in the attached MFR's (Incls 1 & 2) has arisen. T7 temperature is the temperature of the combustion gases at the inlet to the power turbine. The gases have already passed through the high and low pressure turbines, and have cooled considerably in the process. The critical temperature in the engine occurs at the inlet to the high pressure turbine. This temperature is defined as T5 (see accompanying drawing, Incl 3). The material properties of the turbine wheels dictate that the temperature T5 be kept below a given temperature (2180°F). 2180°F yields a power output of 1500 HP on a 100° day. T5 is not measured directly.

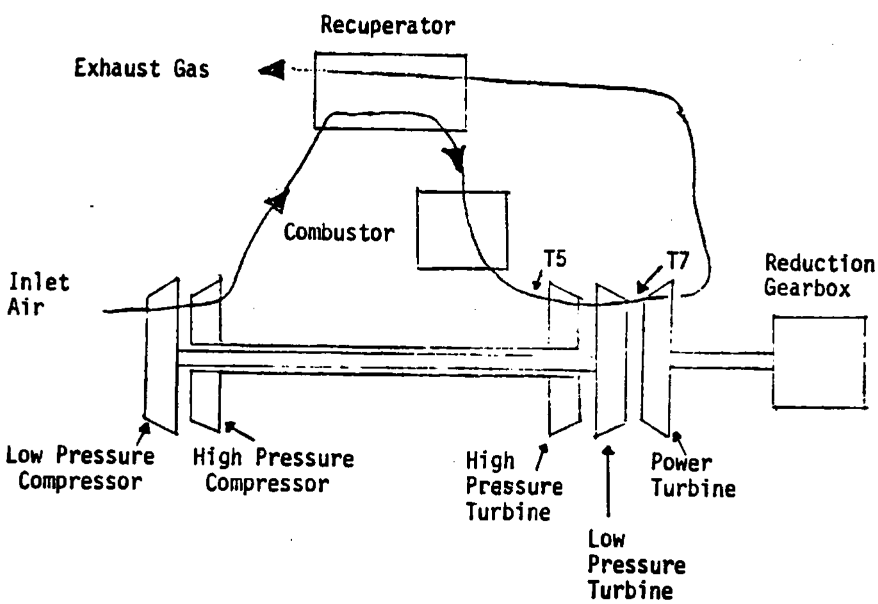
DRCPM-GCM-SM 15 February 1977
SUBJECT: Turbine Overspeed Protection and T7 Temperature Indication for the Turbine Engine

Instead, T7 is monitored, and a T7 temperature of 1450°F corresponds to a T5 temperature of approximately 2180°F. When the T7 temperature exceeds 1450°F, the fuel control system automatically reduces the fuel flow to the engine. This reduces the T5 and T7 temperatures. This system automatically prevents "hot starts", by reducing the fuel flow to the engine if the turbine section is hot (see Incl 2). The T7 temperature sensor also indirectly limits the compressor speed as stated in Paragraph 5. of Incl 1.

Paul M. Root

3 Incl
as

PAUL M. ROOT
MAJ, GS
Automotive Branch


Recuperator
Exhaust Gas
Combustor
T5
T7
Reduction
Gearbox
Inlet
Air
Low Pressure
Compressor
High Pressure
Compressor
High
Pressure
Turbine
Low
Pressure
Turbine
Power
Turbine

/NCL 3

Appendix B-9

DRCPM-GCM

Automotive Branch
22 August 1977

FUEL CONTROL FACT SHEET

1. Background:

a. Nomenclature: Electronic Fuel Management System or Electronic Fuel Control. Bendix Energy Controls Division is the subcontractor.

b. Requirement: The electronic fuel control must meter fuel flow to the engine according to driver's demands, within the limits of turbine inlet temperatures, as necessary to provide high engine durability. It must also govern normal and tactical idle, maximum speed and provide engine overspeed and overtemperature protection.

2. Component Characteristics: The Electronic Fuel Management System consists of three components provided by Bendix (Incl 1). The components and their functions are (Incl 2):

a. T1 Sensor: Senses the temperature of air into the engine.

b. Computer: An analog electronic computer mounted in the driver's compartment which takes inputs from the driver, vehicle, engine, and flow handling modules in the form of electrical signals, processes them, and schedules the fuel appropriately. It does this by sending an electrical signal to the flow handling module. The computer also controls certain engine accessories and provides driver information in the form of a power turbine speed tachometer and warning lights.

c. Fuel flow handling module: (Incl 3) This unit, mounted on the engine accessory gearbox, contains the fuel metering valve which meters the fuel based on the signal from the computer. It also contains a fuel pump and filter and the servos which position the inlet guide vanes and power turbine stator vanes for part load operation. Feedback for the two servos and fuel metering valve feedback are also contained in the module.

3. Schedule: FSED Schedule is at Incl 4.

4. Present Status: Several engineering and FSED prototypes have been delivered to AVCO and are currently being tested on laboratory engines. Development work is continuing and fuel schedules are being optimized. An engineering prototype was installed in engine S/N 26 and accumulated over 1900 miles on the ATR at Chelsea Proving Ground with excellent results. No major problems were encountered and there were no mechanical failures. Work is continuing and component Qualification Testing will begin at Bendix in September. A total of 40 fuel controls will be built during FSED. In June,

DRCPM-GCM
Fuel Control Fact Sheet

22 August 1977

Chrysler was tasked to investigate the feasibility of using current electronics technology for the computer. The computer currently is an analog type and consists of discrete components soldered to printed circuit boards. They were asked to look at such developments as microprocessors, large scale integrated circuits, and analog-digital convertors from a standpoint of possible production cost reduction, reliability effects, and modification of the maintenance concept to one of "throway" modules. This investigation is continuing.

5. Cost:

a. FSED Contract: $2.78 million

b. Production: Ten year design-to-cost for 3312 units is approximately $7500 (Bendix price to AVCO).

6. Personnel:

a. Man loading (average)

FY77	FY78	FY79
15	10	4

b. Number of personnel at Bendix Energy Controls Division: 2376

7. Risk:

a. Technical: Technical risk is low. Bendix, in a very short time, has produced a fuel control that performs extremely well, and based on the limited test data so far, is reliable and durable. The technology used is well established.

b. Schedule: Schedule risk is low. Bendix has met all their milestones, in spite of having a very short lead time to produce the first prototypes.

c. Cost: Cost risk is low. Due to the mature design, cost estimates should be valid.

8. Previous Guidance/Interest:

a. High echelon: None.

b. User: User interest centers on the engine protection capabilities of the fuel control. Many users have had helicopter experience and are familiar with the problems of "hot starts" and having to wait for a period of time to attempt a restart if the initial attempt were unsuccessful. The electronic fuel control has built-in circuitry to prevent hot starts. A second attempt to start may be made as soon as the high speed compressor has coasted down to a low speed after a previous unsuccessful start attempt.

Appendix B-10

DRCPM-GCM-SM 15 August 1977

MEMORANDUM FOR RECORD

SUBJECT: Starting Procedure and Sequence for Turbine Engine

1. Normal Start Procedure and Sequence:

a. Momentarily, with the transmission range selector in neutral, depress the operator "push to start" button on driver's master panel (Incl 1).

b. Start sequence is automatically controlled by the electronic fuel management system which energizes the starter and ignitor and schedules fuel flow to bring the engine to a minimum idle governed speed.

c. A start is normally achieved within 20 to 40 seconds. When the high pressure compressor (N_H) speed reaches 55%, the green "started" light on the master panel comes on for approximately 10 seconds indicating a successful start. When the "started" light goes out, the hydraulic pump is engaged.

d. If a start has not been achieved in 60 seconds, the sequence is automatically terminated.

e. The vehicle can be put in gear before the "started" light comes on, and the vehicle will begin to move as soon as the engine develops enough power to overcome internal losses, but the automatic fuel schedule cannot be overridden, and the driver will not have full control until the "started" light comes on.

2. Normal Engine Shutdown Procedure: An engine shutdown is achieved by moving the engine "shutoff" toggle switch on the master panel to the down position. This switch closes the main engine fuel shutoff valve (i.e., electrical power required to close valve). The toggle switch is automatically (magnetically) held in the down position until 10 seconds have elapsed from the time the engine high pressure compressor speed (N_H) reaches 5% at which time the shutoff switch then snaps back to its up (main fuel valve open) position. It normally takes from 20 to 25 seconds for the engine to coast down from idle with the hydraulic pump installed.

3. Re-start Following a Normal Shutdown (Engine Hot): A restart following a normal shutdown with engine hot can be accomplished immediately, using the "Normal Start Procedure," after the engine "shutoff" switch snaps back to the up position. Circuitry built into the electronic fuel control prevents "hot starts."

DRCPM-GCM-SM 15 August 1977
SUBJECT: Starting Procedure and Sequence for Turbine Engine

4. Start Attempt Following an Automatic Abort:

a. If a successful start has not been achieved within 60 seconds or otherwise automatically aborted, the starter and ignitor are automatically de-energized, the main fuel valve is closed, and the abort light on the master panel comes on. This abort light then stays on until 10 seconds after the time a 5% high pressure compressor (N_H) speed is achieved.

b. A subsequent start, using the Normal Start Procedure above, can be attempted immediately after the high pressure compressor (N_H) reaches 5% speed, but practically speaking, this would not be until the abort light goes off, since there is no indication when N_H reaches 5%.

c. The maximum time available for an automatic start sequence can be extended by manually holding the "push to start" button in throughout the start cycle. If a total of 60 seconds has elapsed when the button is released, the sequence will stop. If less than 60 seconds has elapsed when it is released, the sequence will terminate at 60 seconds elapsed time.

d. There is not requirement currently to turn the engine over with the starter between start attempts in order to purge the fuel accumulated since the automatic drain valve should be of sufficient capacity to discharge any fuel accumulated during an abortive start attempt.

5. Starter Only:

a. The "Starter Only" button on the master panel is useful in trouble-shooting to check such items as:

- Starter
- Engine Coastdown
- Oil Line Leaks
- Oil Pressure

6. There is no requirement to use it in any starting mode.

1 Incl
as

PAUL M. ROOT
MAJ, OrdC

Appendix B-11

DRCPM-GCM-SM 30 May 1978

MEMORANDUM FOR: Chief, Product Assurance and Test Branch (DRCPM-GCM-SP)
Chief, Systems Engineering Division (DRCPM-GCM-S)
Assistant Project Manager for Logistics (DRCPM-GCM-APM)

SUBJECT: Vehicle Loss of Power

1. Vehicles in the field have repeatedly suffered temporary "loss of power" during operations. This has been identified as a "major" problem by the Advance Information System. This memo defines the problem and provides suggested actions for correction.

2. The Engine Electronic Fuel Management System (EFMS) has three fault (or protective) modes built in to protect the engine from damage in case of full or partial failure of engine sensors or accessories. If the fault is a transient one, the driver may reset the fuel control to full operation by a specific sequence of actions. The "fuel control faulty" lights on the driver's panel is illuminated when the engine is in one of these fault modes and also for certain other reasons. None of the above information or explanations are in any of the manuals.

3. Some instances of "loss of power" are due to proper functioning of the EFMS to protect the engine, and some of the others are due to hardware design problems which are being solved presently. The detail of information currently reported to PMO, Chrysler, and AVCO either verbally or in writing (engineering logs, ITR's, etc.) is not adequate to allow diagnosis of the cause, after the fact, of a transient reported "loss of power" and it is very difficult for the contractor or subcontractor to implement corrective action based on this sketchy information.

4. Possible causes of the "loss of power" due to design problems are:

a. Binding/bent/broken PTS or IGV feedback cables, or bending of the end brackets which support them.

b. Intermittent shorts or open circuits in the RVDT (driver's throttle control) or electrical cables to the ECU, engine, or RVDT.

c. Air in fuel system which results in main metering valve being out of position.

d. Fuel starvation due to low or negative fuel pressures.

DRCPM-GCM-SM 30 May 1973
SUBJECT: Vehicle Loss of Power

5. Several actions must be taken to eliminate this problem and/or minimize its impact when it does occur.

a. Tank crewmen must be made aware of the functioning of the EFMS, that fault modes exist, what happens when they occur, and the various conditions that can exist when the "fuel control faulty" light comes on (Inclosure 1).

b. A procedure must be immediately made known to crewmen on action to take if a "loss of power" occurs in order to try to reset the EFMS to full operation (Inclosure 2).

c. Manuals must be modified to inform crews of the existence of fault modes, functioning of the "fuel control faulty" light and reset methods.

d. Tank crewmen and tech reps must be instructed to report in great detail the circumstances, operating conditions, indications, remaining power, etc., on each occurrence of loss of power in order to aid diagnosis of the particular problem (Inclosure 3).

3 Incl
as

PAUL M. ROOT
MAJ, OrdC

EFMS FUNCTIONING AND FAULT MODES

1. The EFMS has three fault (or protective) modes which function as follows:

a. Fault Mode I - If the high pressure compressor speed is less than 55% of maximum and conditions for Fault Mode I occur, the engine will shut down.

b. Fault Mode II - If the vehicle is in drive and N_H is above 55%, if Fault Mode II occurs fuel flow is limited between 70 and 300 lb/hr. This corresponds to a maximum of approximately 600 HP.

c. Fault Mode III - If N_H is above 55%, and Fault Mode III occurs, fuel flow is fixed at 120 lb/hr (approximately 120-130 HP).

2. The identified faults and conditions for each fault mode are as follows:

a. Fault Mode I - This occurs during the start sequence and aborts the start since N_H is greater than 55% if a start is successfully completed. Conditions during the start sequence which can cause Fault Mode I to occur are:

(1) High speed compressor speed sensor (N_H sensor). If there is no signal from both of the N_H sensors 7 1/2 seconds after initiation of the start sequence. If only one sensor is working the system will function normally, but the "fuel control faulty" light will come on.

(2) Power turbine temperature sensors (T_7 pickups). At 25% of N_H, if the T_7 sensors read less than 225°F or more than 1800°F.

(3) Main fuel valve. At 7 1/2 seconds into the start sequence, if the main fuel valve is out of position by more than + or - 100 lb/hr of the demanded flow for more than 1/2 second.

(4) Power Lever Actuator (PLA). At 7 1/2 sec into the start sequence, if the PLA is set at less than 2° or more than 75° of rotation. These limits are outside the normal rotational limits of the PLA.

(5) Vehicle power supply voltage below 8 volts.

b. Fault Mode II. This will occur when the engine is running and the transmission is in gear. There is limited throttle response in this fault mode. Conditions which can cause Fault Mode II to occur are:

(1) No power turbine speed signal (N_{PT}) from either N_{PT} sensor. If one sensor is working, the system will function normally, but the "fuel control faulty" light will come on.

(2) The inlet guide vane (IGV) or power turbine stator (PTS) cables are jammed, broken, or momentarily hung up.

(3) No power turbine temperature (T_7) signal. When Fault Mode II occurs, it is because the engine has lost one of the above signals which is normally used to control fuel flow. Since there is no signal, fuel flow is reduced to a much lower maximum rate (300 lb/hr maximum, corresponding to approximately 600 HP) to protect the engine. The power turbine stators and the inlet guide vanes are in fixed positions.

c. Fault Mode III. This will occur when the engine is running, whether or not the transmission is in gear. It is designed to avoid complete engine shutdown if certain required input signals are lost, and it gives a fixed fuel rate of 120 lb/hr (approximately 125 HP). There is <u>no</u> throttle response in this fault mode. Conditions which give Fault Mode III are:

(1) Main fuel valve. If it is out of position by more than + or - 100 lb/hr for more than 1/2 second.

(2) System voltage less than 8 volts.

(3) PLA. If it is set at less than 2° or more than 75° of rotation.

These are some of the same faults which will cause Fault Mode I to occur during the starting procedure.

d. All of the above conditions will activate the "fuel control faulty light" and "master caution light".

e. It must be noted that, for vehicle safety reasons, Fault Mode II occurs only with the transmission in gear. If the transmission is shifted to neutral, Fault Mode II automatically becomes Fault Mode III.

3. The "fuel control faulty" and "master caution" lights will also come on, but not affect power or cause a fault mode under certain other circumstances. In these cases, the lights serve as a signal that organizational maintenance should check the engine for loss of a backup sensor:

a. Loss of one of the two N_H sensors. The system functions normally with only one sensor. However, if the second one is lost, a fault mode II results.

b. Loss of one of the two N_{PT} sensors. Same as a above.

c. Loss of the ambient air (T_1) sensor. If this signal is lost, the control assumes that the ambient temperature is 125°F. The fuel is scheduled to the engine as if that were the temperature, and in some cases this results in a slight loss of power at the high power end.

4. "Loss of power" may also be sensed by the driver, if the engine is protecting itself against "overspeed" or overtemperature" conditions. This is normal operation of the EFMS.

a. Overspeed: If an overspeed condition occurs (N_{PT} greater than 3240 RPM) the "overspeed" and "master warning" lights go on and fuel is cut back until N_{PT} is 2350 RPM. Then normal operation can automatically be resumed. The "overspeed" and "master warning" lights can then be turned off by using the reset button. Procedures in the Operator's Manual should be followed.

b. Overtemperature:

(1) Engine steady state operating conditions: If T_7 reaches 1435°F under steady state speed conditions for the high speed compressor, fuel is cut back to maintain 1435°F. No warning light comes on.

(2) Engine acceleration or transient conditions: If T_7 reaches 1620°F during transient, the "overtemperature" and "master warning" lights come on. Fuel flow is automatically cut back until T_7 reaches 1420°F when normal operations can be resumed. Pushing the reset button turns off the lights.

CONDITIONS TO LOOK FOR WHEN "LOSS OF POWER" OCCURS

1. Did "fuel control faulty" or "overspeed" or "overtemperature" lights come on?

2. Operating conditions when "loss of power" was sensed:

   a. Idle or moving.

   b. Previous operating condition.

   c. Speed.

   d. Accelerating or decelerating.

   e. Power turbine speed.

   f. Total or partial loss of throttle response.

   g. Top speed attainable after "loss of power" occurred.

   h. Was the fault resetable?

   i. The procedure used to attempt to reset the fault.

3. These should be described in as much detail as possible to the organizational mechanic (or date recorder) to enable efficient trouble-shooting of any problem.

RESET PROCEDURES FOR FUEL CONTROL

1. If the fault mode was due to a transient condition (i.e., momentary hanging up of the IGV/PTS cables or electrical intermittent in the RVDT or electrical harnesses, etc.) the EFMS may be reset to full operation provided the cause of the fault mode has disappeared.

2. The reset procedures are as follows:

a. If transmission is in gear.

(1) Bring throttle to idle position. The EFMS cannot be reset unless the throttle is in idle position.

(2) Leave transmission in gear.

(3) Push reset button on driver's alert panel and hold for 10 seconds.

(4) If "fuel control faulty" light goes out, the fault was transient and fuel control has been reset to normal operation.

b. If transmission is in neutral.

(1) Put transmission in drive.

(2) Bring throttle to idle position.

(3) Push reset button and hold for 10 seconds.

(4) If "fuel control faulty" light goes out, fault was due to a transient condition and fuel control has been restored to normal operation.

c. If the above fail, shut down the engine, conduct a normal restart and see if normal operation has been restored.

d. If none of the above actions work, the fault was probably not transient. Depending on circumstances, organizational maintenance should be called, or operation should be continued under reduced mobility.

Appendix B-12

DRCPM-GCM-SM | FACT SHEET | Automotive Branch
MAJ Root/31231
25 June 1979

SUBJECT: M60A1(RISE) and XM1 Fuel System

Program Manager, XM1 Tank System

PURPOSE: To compare the XM1 and M60A1(RISE) fuel systems.

FACTS:
1. There have been recent occurrences of XM1 FWS (Fuel Water Separator) filter elements clogging under conditions where M60(RISE) FWS filter elements do not. A change to greater capacity filter elements has not alleviated the problem.

2. In the XM1 fuel system, the FWS is the primary fuel filter and there is a final filter mounted on the engine. Pressure to the FWS is 26 psi maximum (Incl 1). In the M60A1(RISE) fuel system, there is a primary fuel filter ahead of the FWS and the fuel then goes through the engine fuel pump which raises the pressure to 70 psi before entering the FWS (Incl 2).

3. The higher pressure fuel entering the M60A1(RISE) FWS allows a greater buildup of contaminants on the filter elements prior to restricting fuel flow to a point which reduces engine power. However, M60A1(RISE) primary fuel filter clogs often.

4. The M60A1(RISE) Organizational Maintenance Manual (TM 9-2350-257-20-1) lists primary fuel filter replacement as a quarterly service, the two outer filter elements of the FWS semiannually, and the center FWS element annually. The M60 and M60A1(Manual (TM-2350-215-20) requires replacement of the outside FWS elements quarterly and the center element annually. There is no advanced indication that fuel filters are clogging. Checking for clogged fuel filters is a troubleshooting step if the engine won't start, doesn't run properly or runs rough and misfires.

5. According to the XM1 Organizational Maintenance Manual, the fuel water separator is serviced when the fuel filter clogged light comes on (tactical situation permitting) or at scheduled services. The outside elements are replaced semiannually and the center element is replaced annually. "Loss of power, fuel control faulty not lit" and "engine crank

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SUBJECT: M60A1(RISE) and XM1 Fuel System

but will not start" are symptoms for which the FWS clogged light should be checked as part of the troubleshooting procedures.

6. The lack of a primary fuel filter ~~ahead~~ Below of the FWS AND 24 psi FUEL PRESSURE in the XM1 probably accounts for its tendency to clog as oftn as it does. Without the primary filter, replacement of FWS filter elements should be expected prior to S-services.

2 Incl
as

E. W. TRAPP
C, Systems Engineering Division

PROGRAM MANAGER ACTION:

NOTED:_______________

SEE ME:_______________

Appendix B-13

XM1 INDICATOR LAMPS

INDICATOR	MALFUNCTION IDENTIFIED	REQUIRED CREW ACTION
1. Driver's Alert Panel a. Master Warning	Activates whenever a red warning light illuminates on Driver's Instrument Panel.	Driver should check his Instrument Panel to identify specific warning lamp activated.
b. Master Caution	Activates whenever a yellow caution light on Driver's Instrument Panel or Master Panel illuminates (will not illuminate for engine abort).	Driver should check his panels to identify specific caution lamp activated.
2. Driver's Instrument Panel a. Warning Lamps (1) Engine Oil Temp High	When engine is running light activates if engine oil temperature is too high.	Driver should decrease speed to lower oil temperature. If light goes out continue operation. If light remains on shut down engine immediately and notify Organizational Maintenance.
(2) Engine Oil Pressure Low	When engine is running light activates when engine oil pressure drops below a certain value. Engine will automatically shut down when light activates.	Notify Organizational Maintenance.
(3) Engine Overspeed	When engine is running light activates when output shaft speed exceeds 3240 RPM. Engine speed automatically decreased by fuel control.	Driver should depress reset button on Alert Panel. If lights go out continue operation. If lights remain on shut down engine and notify Organizational Maintenance.

INDICATOR	MALFUNCTION IDENTIFIED	REQUIRED CREW ACTION
(4) Engine Gas Overtemp	When engine running light activates when gas temperature exceeds safe operating value. Engine speed automatically reduced by fuel control.	Driver should depress reset button on Alert Panel. If lights go out continue operation. If lights remain on shut down engine and notify Organizational Maintenance.
(5) Transmission Oil Temperature High	Light activates with engine running when oil temperature exceeds 310^{o}F.	Driver should decrease speed to lower temperature. If light goes out continue operation. If light remains on shut down engine and notify Organizational Maintenance.
(6) Transmission Oil Pressure Low	With engine running light activates if transmission oil pressure drops below safe value.	Driver should decrease speed if light goes out continue operation. If light remains on shut down engine and notify Organizational Maintenance.
(7) Engine Fire	With Master Power On light will flash if engine compartment fire sensors detect a fire after automatic discharge of engine 1st shot extinguisher. Master warning light on Alert Panel will also flash.	Driver should notify tank commander of engine fire and prepare to manually discharge engine 2nd shot extinguisher bottle upon tank commander's order. Engine will automatically shutdown on second shot activation. Notify Organizational Maintenance of fire at first opportunity.
(8) Service/Parking Brake (Driver's Master Panel)	Light will activate with Master Power on and following conditions exist: Parking brake is on, Service Brakes are on for over two minutes.	Driver should check to see that Parking and Service Brakes are off. If brakes are off and light remains on, notify Organizational Maintenance.

INDICATOR	MALFUNCTION IDENTIFIED	REQUIRED CREW ACTION
b. Caution Lamps		
(1) Low Fuel Level	Light will activate with Master Power on when fuel in rear tank reaches 1/4 full.	Driver should transfer fuel from front tanks or refuel vehicle.
(2) Low Battery Charge	With Master Power on light will activate when battery voltage falls below 23 volts. 23.7.	If engine is off driver should restart vehicle to charge vehicle batteries. If engine is on when light activates notify Organizational Maintenance.
(3) Fire Extinguisher 1st Shot Discharge	With Master Power on light will activate upon discharge of 1st shot bottle.	Driver notify tank commander. Notify Organizational Maintenance to replace bottle.
(4) BITE Monitors		
(a) Engine Oil Low	With Master Power on, engine off, light activates if engine oil quantity is one gallon or more low. *	Add engine oil per DLO 9-2350-255-12. changed per production
(b) Cable Disconnect	With Master Power on light will activate if major hull electrical harness is disconnected (except main power and GFE).	Check mating of hull electrical harness connectors.
(c) Intercom Inoperative	Checks power on distribution side of turret power circuit breaker 2 in Hull Power Distribution Box.	
(d) Battery Water Low	Inoperative	N/A.
(e) Circuit Breaker Open	With Master Power on will activate if one or more hull circuit breakers are open.	Check position of all hull manually activated circuit breakers and reset as necessary. If a circuit breaker(s) will not stay on notify Organizational Maintenance.

INDICATOR	MALFUNCTION IDENTIFIED	REQUIRED CREW ACTION
(f) Transmission Oil Level Low	With Engine Running light will activate when transmission is two or more gallons low on oil.	Add transmission oil per DLO 9-2350-255-12.
(g) Engine Oil Filter Clog.	With engine running light will activate when pressure drop across filter exceeds a specific value.	Notify Organization Maintenance at first opportunity. If on a mission, complete mission.
(h) Transmission Oil Filter Clog	With engine running light will activate when pressure drop across filter exceeds a specific value.	If on a mission,complete mission. Notify Organizational Maintenance at first opportunity.
(i) Fuel/Water Separator Clog	With engine running light will activate when pressure dropp across filter exceeds a specific value.	If on a mission, complete mission. Notify Organizational Maintenance at first opportunity. (Vehicle will experience a power loss as filter pressure drop increases.) ?
(j) Air Cleaner Filter Clog	With engine running light will activate when pressure drop across V-Pacs exceeds a specific value.	If on a mission, complete mission or clean filters per DEP-9-2350-255-10-1 if mission permits. Crew cleaning is an interim measure and Organizational Maintenance should be notified at first opportunity. Vehicle will experience a loss of power as filters clog. Light will flash during high engine speed operation and go out at low speed or idle operation.

INDICATOR	MALFUNCTION IDENTIFIED	REQUIRED CREW ACTION
(k) Rear Fuel Pump Inoperative Left and Right.	Light activates when engine is running and pump pressure drops below a preset value.	Driver should check circuit breakers if pump and circuit breaker lamps activates. Vehicle will operate on a single pump. Notify Organization Maintenance at first opportunity.
(l) Fuel Control Fault	With engine on light will illuminate if engine Electronic Control Unit (ECU) detects a control or sensor problem.	Engine will automatically enter a fault mode with possible noticeable loss of power. Driver should attempt to clear fault by depressing reset button on alert panel. If light goes out,continue operation. If light remains on,notify Organizational Maintenance at first opportunity.
(m) Hydraulic System Malfunction	Light activates with low flow through hydraulic pump case drain.	Notify Organizational Maintenance at first opportunity.

APPENDIX C

Appendix C-1

DRCPM-GCM-SM | INFORMATION PAPER | Automotive Branch
MAJ Root/31231
2 February 1979

SUBJECT: Fuel Consumption

1. Estimating the fuel consumption for a tank is like estimating the fuel consumption for an automobile; there is no single valid number.

2. Fuel consumption depends on many variables, including:

   a. Engine and transmission condition.

   b. Terrain (sand, mud, wet, dry, paved, etc.).

   c. Track condition and tension (rolling resistance).

   d. Slopes.

   e. Driver technique (heavy foot, etc.).

3. Fuel consumption data is becoming available from several sources. Each source represents a significantly different condition and will be tabulated and discussed below. The data can be combined and manipulated in various ways to approximate an overall average (typical?) fuel consumption.

   a. Development Test data is tabulated below. It is taken from tests conducted on primary and secondary straight level roads using fuel burettes under controlled conditions. It is probably representative of the potential of the system and has as many variables removed as possible.

Paved	10 MPH	15 MPH	20 MPH	25 MPH	30 MPH	35 MPH	40 MPH
DT II Test	.41 MPG	.44 MPG	.54 MPG	.64 MPG	.70 MPG	.72 MPG	.71 MPG
PMO Prediction	---	---	---	.67 MPG	---	---	---

Secondary							
DT II Test	.38 MPG	.42 MPG	.45 MPG	.56 MPG	.65 MPG	.63 MPG	.58 MPG
PMO Prediction	---	---	.49 MPG	.55 MPG	---	.59 MPG	---

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b. Cross country fuel consumption data currently available states that XM1 achieves .30 MPG cross country. This is actually DT I data supplied by TECOM. It is an average of all the miles run and fuel consumed during the DT I cross country endurance running on level and hilly cross country courses at APG. It includes idle time, does not account for fuel spillage, and was not run at any specific given speed. As such, it is gross data. Because TECOM publishes cross country fuel consumption data based on the above technique, this figure will not be updated until the end of DT II. TECOM has been asked to conduct a specific cross country fuel consumption test over certain courses at discrete speeds in an attempt to get better cross country data for varying speeds. Because of the differences in "cross country" terrain, this data will only be completely valid for the given courses but should be a better estimate than the previous one.

4. Comparative data with M60 (RISE) has been run in DT II on the standard fuel course (hilly secondary road) at APG. This data is listed below and is a valid comparison for that course only. The M60 is seven tons lighter and has an engine with half the power of the XM1 and consequently less mobility. The comparison ends at 24 MPH because that was the M60's top speed.

	10 MPH	15 MPH	20 MPH	24 MPH	30 MPH
XM1	.28 MPG	.32 MPG	.38 MPG	.40 MPG	.37 MPG
M60 (RISE)	.65 MPG	.65 MPG	.64 MPG	.59MPG	-----*

*M60 top speed was 24 MPH.

The ratio of fuel consumption for the XM1 and M60 based on the comparative test course is as follows:

	10 MPH	15 MPH	20 MPH	24 MPH
Ratio	2.32	2.03	1.68	1.47

5. Idle fuel consumption tests have been run during DT II. The idle fuel consumption has been 10.3 - 10.8 gal/hr at 1000 - 1020 RPM. This speed is higher than the specified engine idle speed of 870 - 950 RPM, and the test will be rerun at the lower speed. A reduction in idle fuel consumption is expected.

6. Operational Test fuel consumption data is becoming available from Ft. Bliss.

a. The figures listed below represent data for the operational test profile and are taken from fuel tankers and vehicle logbook records. No

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allowance is made for spillage or leakage. The data represents overall fuel consumption for a variety of missions including motor pool, gunnery, tactical exercises and road marches for five tanks. M60 (RISE) was run to approximately the same missions, so the comparative data (gallons per mile) should be a rough estimate. (M60 is lighter and has half the power and less mobility). It should be noted that approximately 62% of the engine operating time for XM1 is at idle, an inefficient operating condition when compared to the ~~turbine~~ DIESEL.

OT II Fuel Consumption 17 NOV-13 Dec 78

	Gal	Miles	Gal/Mile	Mile/Gal
XM1	9891	2507	3.94	.25
M60 (RISE)	6166	2720	2.27	.44

Based on this, the XM1 uses 74% more fuel than the M60 (RISE)

b. Several discrete fuel consumption tests were run at Ft. Bliss to gather fuel consumption data over specific courses and comparison with M60 (RISE). The tests were conducted in late January 1979 with several XM1 and M60 (RISE) tanks operating in each condition and the data was provided to the PMO. Automotive Branch, PMO, reviewed the data, found some monor computational errors, and the corrected data is presented below: This data is valid for the conditions which existed at Ft. Bliss at the times of test. Figures are averages for several tanks. Ratios are gallons/mile which is the valid method for comparing fuel consumption. Note that XM1 speeds are greater than M60 speeds.

(1) Paved road.

	Speed (MPH)	Gallons	Miles	Gal/Mile	Mile/Gal
XM1	35	94.3	53.2	1.77	.56
M60	25	50.0	60.3	1.21	.82

Under the above conditions, XM1 uses 46% more fuel.

(2) Secondary road. A "secondary road" is widely variable from hard clay to gravel, to soft wet sand or mud.

(a) Course S1. Motor park to Coal Lake. Uphill (10% grade?). Muddy, slippery road.

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	Speed (MPH)	Gallons	Miles	Gal/Mile	Miles/Gal
XM1	20	36.3	10.6	3.42	.29
M60	17.4	23.1	10.6	2.17	.46

XM1 uses 58% more fuel under this condition.

(b) Course S2. Tank trail in area MAS. Muddy, slippery loop of secondary road.

	Speed (MPH)	Gallons	Miles	Gal/Mile	Miles/Gal
XM1	24.9	20.9	11.7	1.78	.56
M60	17.0	19.6	11.7	1.67	.60

XM1 uses 11% more fuel under this condition.

(c) Course S3. A second circuit of the tank trail used in S2. Soil was churned up by previous use of trail.

	Speed (MPH)	Gallons	Miles	Gal/Miles	Miles/Gal
XM1	24.6	39.1	14.0	2.80	.36
M60	19.4	26.3	14.0	1.88	.53

XM1 uses 49% more fuel under this condition.

(d) The wide differences in XM1 fuel consumption between Courses S2 and S3 seem unreasonable.

(3) Cross country. There is no definition of standard cross country terrain.

(a) Course C1. Maneuver area 6 with high hills and deep sand. Course was wet and heavy.

	Speed (MPH)	Gallons	Miles	Gal/Miles	Miles/Gal
XM1	12.5	92.5	14.2	6.51	.15
M60	8.8	68.3	14.2	4.81	.21

XM1 uses 35% more fuel under this condition.

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(b) Course C2. Run in same area as C1.

	Speed (MPH)	Gallons	Miles	Gal/Miles	Miles/Gal
XM1	11.2	88.2	22.8	3.87	.26
M60	9.3	59.6	22.8	2.61	.38

XM1 uses 48% more fuel under this condition.

7. Mission profile fuel consumption has also been addressed.

a. A Mission profile usually consists of segments of idle, secondary road and cross country travel. There is a lack of a universally accepted mission profile. Mission profile fuel consumption is affected by idle time and the average speeds at which the vehicle operates. The data upon which the computations are based is usually the DT II data for the average speed for secondary road travel and the DT I value (.30 MPG) for cross country, regardless of speed.

b. A reasonably accepted mission profile (used in COEA) consists of 172.8 miles of operation in a 24 hour day. Distances, operating times and speeds are given, and the results are given below:

XM1	Speed	Time	Consumption Rate	Total Fuel
Idle	0	5.17 Hrs	10.8 Gal/Hr	55.8 Gal
Cross Country 66.6 Mi	17 MPH	3.92	.30 MPG	222.
Secondary Rd 106.2	25 MPH	4.25	.56 MPG	189.6
TOTAL		13.35 Hrs		467.4

M60 (RISE)	Speed	Time	Consumption Rate	Total Fuel
Idle	0	3.4 Hrs	5.3 Gal/Hr	18.0 Gal
Cross Country 66.6 Mi	14.4 MPH	4.63 Hrs	.52 MPG	127.3
Secondary Rd 106.2	20 MPH	5.32 Hrs	.43 MPG	218.1
TOTAL		13.35 Hrs		363.4 Gal

c. Based on this profile, XM1 uses 29% more fuel than M60 (RISE). This profile assumes equal engine operating time and equal distance covered. Due to the higher speeds possible in XM1, it arrives at its destination in less time than M60. To achieve equal operating time, the XM1 idles 1.77 hours more than M60. This does not seem to be reasonable, and an alternative mission profile could assume equal idle time and equal distance. Under this condition, using above mileages and speeds and 3.4 hours of idle time for both vehicles, XM1 consumes 23% more fuel than M60 (RISE).

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d. Many other profiles are possible resulting in widely varying battlefield day fuel consumptions and comparisons between vehicles.

8. From the above, it can be seen that there is no single fuel consumption, or even an absolute average fuel consumption, and comparisons with M60 (RISE) vary widely depending on operating conditions. The following figures summarize the ranges of fuel consumption and comparisons with M60 (RISE) based on the limited testing to date.

a. Fuel consumption figures for XM1. (The range of results is shown).

(1) Paved (35 MPH) .56 - .71 MPG.

(2) Secondary (25 MPH) .36 - .56 MPG.

(3) Cross country (12 - 18 MPH) .15 - .30 MPG.

(4) Idle 10.3 - 10.8 gallons per hour.

b. Comparison with M60 (RISE). (Comparisons are at different speeds for XM1 and M60).

XM1 uses:

(1) Paved: 46% more.

(2) Secondary: 11 - 58% more.

(3) Cross country: 35 - 45% more.

c. Mission profile fuel consumption depends on the selected profile.

9. Any of the above data should be viewed as very tentative and used judiciously.

10. Further fuel consumption testing should be performed in a variety of climates and terrains to refine and gain more confidence in the figures.

E. W. TRAPP
C, Systems Engineering Division

Appendix C-2

WHITE PAPER

SUBJECT: MG Lynch's Fuel Consumption Comments

1. MG Lynch is concerned that the XM1 may have a range significantly below the MN requirement.

2. The MN requirement for vehicle operating range is 275-325 miles on dry, zero slope secondary road. Fuel consumption is tested at Aberdeen Proving Ground using calibrated fuel measuring equipment. The tank is run several times over a relatively short course and the average fuel consumption rate is determined. This consumption rate and the fuel tank useable capacity are used to compute vehicle range. This test will provide a degree of repeatability and reduce the number and influence of uncontrolled variables which could affect the results. It should be noted that "operational" cruising range will always be significantly less than the range measured in this manner.

3. DT I testing resulted in a secondary road, 25 MPH, fuel consumption of 0.51 MPG. This was conducted using DF-1 fuel and when the results were corrected for the higher heating value of DF-2 fuel, the result was 0.53 MPG. A later test in DT I resulted in 0.53 MPG, which when corrected for DF-2, yielded 0.55 MPG.

4. DT II testing in November 1978 resulted in a secondary road, 25 MPH, fuel consumption of 0.56 MPG using DF-2 fuel. The fuel capacity of the pilot vehicle used was 482 gallons resulting in a cruising range of 270 miles which is marginally below the MN requirement. Production tanks will have a capacity of approximately 500 gallons.

5. There has been recent concern that the increased track tension now used will decrease cruising range. A fuel consumption test was run on PV8 at APG during 12-18 December 1979 on both paved and secondary road and on the standard fuel consumption course. The test showed that the effect of the increased track tension was to increase fuel consumption from 8.4% to 11.1%, depending on the course. This is close to the 10% increase measured in an earlier test. The unexpected result of this test was that the absolute vehicle fuel consumption on secondary road at the low track tension was much less than during the original test and, even at the high track tension, PV8, as tested, met the 275 mile cruising range requirement (.567 MPG x 491 gallons available in PV8 = 278 miles) (see Incl 1). PV8 weighed 58.5 tons during this test. Production vehicles will weigh 59.8 tons. Decreasing fuel consumption by the increased weight yields 0.554 MPG and a range of 272 miles which is marginally below the requirement.

SUBJECT: MG Lynch's Fuel Consumption Comments

6. The exact cause for this improvement in fuel consumption is unknown, but is probably due to a combination of engine condition, secondary road condition, ambient temperature, driver skill, transmission performance, the use of integral pad track instead of replaceable pad track, and the fuel specific heat value. Since the fuel consumption on paved road at the lower track tension was nearly the same in both the November 1978 and December 1979 tests, (2.7% better in the latter test), the secondary road condition probably had the greatest influence on the results (see Incl 1). The secondary road was probably in a "harder", drier condition for the second test.

7. The bare engine fuel consumption of the engine used for this test will be measured at AVCO and Chrysler is conducting an analysis of the engine, transmission and suspension with regards to fuel consumption.

8. The conclusion that the increased track tension increases fuel consumption by about 10% seems to be proven; however, further testing might be advisable. The difference in results of tests on secondary road highlights the difficulty of repeating the secondary road conditions. Both the early and recent sets of results are valid, only the secondary road conditions varied. Repeatability would be enhanced by doing fuel consumption testing on paved road where conditions vary less. DT III testing should provide the best answer as to the fuel consumption with higher track tension.

9. There will always be some variation in results of this type of test. Even the EPA cannot give fuel consumption figures for automobiles which are repeatable by consumers. The EPA provides a caution about the use of its figures and the same cautions would apply here. There are too many variables from tank to tank and test to test to expect complete repeatability and, in actual operations, the greatest factor influencing range will be how the driver handles his tank.

10. The MN cruising range should not be confused with an "operational" cruising range which might be defined as the range which a tank can be driven in a field environment without refueling, and which will always be less than the MN cruising range. Vehicle accelerations and decelerations, slopes, turns, the rolling resistance of various terrains, periods of engine idle, driver skill, and other uncontrollable factors all contribute to an "operational" cruising range less than that measured for the MN requirement on a flat secondary road.

11. The "operational" cruising range quoted in the Phase I Ft. Knox test results 3.8 GPM yielding a range of 140-160 miles, is based on total vehicle mileage (12,930 miles) and total fuel consumed during the test. The data was collected in a relatively uncontrolled manner and includes unknown periods of idle time and does not account for fuel spillage or the accuracy of the fuel metering devices. Nonetheless, this data is comparable to the data taken in a similar manner from OT II at Ft. Bliss during 17 November-13 December 1978 of 3.9 GPM and may represent a reasonable planning figure.

SUBJECT: MG Lynch's Fuel Consumption Comments

12. This "operational" range will vary from unit to unit and tank to tank and can be improved by training the driver to conserve fuel by such actions as reducing engine idle time, eliminating maximum power accelerations, etc.

13. There are two future developments which will affect fuel consumption. The APU installation will result in a loss of 50 gallons of fuel in the left sponson fuel tank. The 120mm gun program will increase the vehicle weight to approximately 61.5 tons, increasing fuel consumption. Part of the 120mm program is to increase the capacity of the left front fuel tank by 35 gallons. The effect of the increased weight and increased fuel capacity practically cancel each other out and vehicle range is nearly unchanged. The fuel lost to the APU will reduce the MN range; however, the effect on the "operational" range will be minimal because the APU can substitute for periods of engine idle.

PAVED ROAD

Adjusting Link Pressure	DT II Nov 78	Track Tension Test Dec 79	Track Tension Test Corrected to 59.8 T
1800 psi	.625 MPG	.642 MPG	.628 MPG
2200		.626	.612
2600		.592	.579
3000		.588	.575

SECONDARY ROAD

Adjusting Link Pressure	DT II Nov 78	Track Tension Test Dec 79	Track Tension Test Corrected to 59.8 T
1800 psi	.56 MPG	.628 MPG	.614 MPG
2200		.599	.586
2600		.592	.579
3000		.567	.554
Fuel Capacity	482 Gal	491 Gal	491 Gal
Range at current track tension	270 Miles	278 Miles	272 Miles

Appendix C-3

DRCPM-GCM-SM | INFORMATION PAPER | Automotive Branch
MAJ Root/31231
8 March 1979

SUBJECT: Comparative 1500 HP Engine Fuel Consumption in XM1

1. Fuel consumption for the 1500 HP AGT 1500 turbine and AVCR 1360 diesel engines was computed based on the mission profile defined in TSM Message 131608Z Feb 79, Subject: XM1 Fuel Consumption. The mission profile and resulting fuel consumptions are listed at Inclosure 1.

2. Based on this data, the turbine engine consumes from 9.4% more to 1% less fuel than the diesel. The variation is based on the fact that on secondary road, 25 MPH was the shift point between 3d range converter and lockup and the ~~vehicle~~ diesel could be in either condition at 25 MPH.

3. The AVCR 1360 diesel engine was tested in the General Motors prototype XM1 in Validation at a weight of 58 tons. The diesel fuel consumption is based on DT I test results.

4. The AGT 1500 turbine engine fuel consumption is based on DT II test results at a vehicle weight of 59.8 tons with one exception. The cross country fuel consumption is based on DT I results. This is due to MTD's method of collecting cross country fuel consumption data, and comparable DT II data will not be available until the end of DT II.

5. The above comparison is for vehicles of different weights: 58 tons for the diesel and 59.8 tons for the turbine. To provide a valid comparison based on the present XM1 configuration, the diesel fuel consumption must be adjusted for the increased weight of the present XM1 vehicle. To do this, the fuel consumption rates for the diesel in motion are increased (MPG are decreased) by the ratio of the upweighted diesel XM1 to the DT I data taken at 58 tons. There are two ways to approach this:

a. Equal vehicle weight of 59.8 tons. The mission profile fuel consumption becomes 413-373 gallons, a difference for the diesel of 6.2% better to 4.3% worse than the turbine. Because of the heavier weight of the diesel power pack, nearly 2000 lbs, this configuration would result in nearly a ton less armor and consequently less protection than the present turbine XM1

DRCPM-GCM-SM 8 March 1979
SUBJECT: Comparative 1500 HP Engine Fuel Consumption in XM1

b. Equal protection levels. This assumes that equal armor protection is retained. The additional diesel power pack weight is added to the existing vehicle weight resulting in a 60.8 ton vehicle. This results in a diesel fuel consumption range from 417-378 gallons for the above mission profile, a difference for the diesel of 4.8% better to 4.9% worse than the turbine.

5. Conclusions:

a. Fuel consumption and the relative difference will vary with the mission profile chosen.

b. The increased weight of the diesel engine installed in the present XM1 has only a minor effect on the diesel fuel consumption.

1 Incl
as

E. W. TRAPP
C, Systems Engineering Division

TRADOC MISSION PROFILE

		AVCR 1360 (DT I-58 Tons)	AGT 1500 (DT II 59.8 Tons)
Secondary Road @ 25 MPH	85 Mi	.48 - .61 MPG**	.56 MPG
Cross Country @ 17 MPH	56.4 Mi	.31 MPG	.30 MPG*
Idle	5.17 Hrs	7.9 Gal/Hr	10.8 Gal/Hr
		400 - 362 Gal	396 Gal

*DT I Results

**Lower value in 3d converter. The test was rerun by accelerating to 27 MPH where transmission went into 3d lockup and then backing off the throttle, yielding the higher value.

Appendix C-4

Sup

XM1

Q. How does XM1 Fuel Consumption compare with the current fleet of tanks (M60(RISE))?

A. I expect the XM1 to consume on the average about 50% more fuel than the M60(RISE) tank. However, because the fuel consumption of the XM1's 1500 HP turbine engine is more sensitive to idle and low speed operation than the M60(RISE)'s 750 HP diesel engine, this value can range from extremes of 25 to 80 percent depending on how one defines the mission profile.

The Army is not satisfied with this and has initiated a turbine engine fuel economy program to achieve a 10% reduction in fuel consumption. If the Army approves a requirement for an Auxiliary Power Unit for each tank, an additional 3-4% cut in daily mission profile fuel consumption can be expected.

- - - -

Basis for Expectations:

50% Estimate:
- OTEA: OT II subtest in Jan 79 (DCSRDA request) to determine comparative consumption rates for XM1 and M60(RISE) when operated over varied terrain and conditions, i.e., roads, cross country and idle (XM1 completes mission in 80% of time it takes M60).

	Ttl Miles	Hrs	Gallons	Ratio XM1/M60
XM1	126	8.24	398.3	1.5
M60(RISE)	126	10.18	265.8	-

- OTEA: OT II fuel subtest fitted to TRADOC time profile of 13.34 hrs (for XM1) and distance of 141.7 (XM1 completes mission in 86% of time it takes M60).

	Miles	Hrs	Gallons	Ratio XM1/M60
XM1	141.7	13.34	569.7	1.57
M60(RISE)	141.7	15.56	361.8	

25% Estimate:
- TRADOC: Application of DT II fuel consumption data to COEA constant mileage profile: 24 hr period of intense combat recognizing XM1's mobility advantage (XM1 completes mission in 88% of time it takes M60).

	Miles	Hrs	Gallons	Ratio XM1/M60
XM1	172.9	13.34	467.3	1.24
M60(RISE)	172.9	15.11	377.0	

80% Estimate:
- OTEA: Gross 1/ OT II fuel consumption data for period 17 November 1978 to 23 January 1979.

	Miles	Gallons	Gal/Mi	Ratio XM1/M60
XM1	5059	17,092	3.38	1.82
M60(RISE)	4380	8,162	1.86	

1/ Values based on odometer reading and log book entries for period. No controls on mode of operation, idle time, spillage, and fuel metering.

DT FUEL CONSUMPTION DATA

(General Rogers testimony)

General Rogers: The following chart shows the speeds at which we conducted the fuel consumption tests at Aberdeen Proving Ground. The fuel consumption value for each condition is also indicated. The value for the secondary road condition at 25 mph, i.e. .56 mpg, is the basis for computing XM1 range.

Condition	Speed						
Paved	10 MPH	15 MPH	20 MPH	25 MPH	30 MPH	35 MPH	40 MPH
DT II Test	.41mpg	.44mpg	.54mpg	.64mpg	.70mpg	.72mpg	.71mpg
Secondary							
DT II Test	.38mpg	.42mpg	.45mpg	.56mpg	.65mpg	.68mpg	.68mpg

- Discrete tests
- Slightly better than predicted
- Best economy at higher speeds

Cross Country - Not yet computed
Based on all endurance running in DT II
Uncontrolled test
Available at end of DT II

Discrete Cross Country Test at APG .26 MPG

Fort Knox fuel consumption tests

	XM1	M60
Secondary Road	.45mpg	.62mpg
Cross Country	.25mpg	.41mpg

Side by side tests
Heavy cross country
Hilly secondary road
Steering

OT Fuel Consumption

Early data was very inaccurate

- no controls
- inaccurate logbooks
- fuel meters on fuel trucks non-functional
- unknown amounts of idle time, speeds

Discrete tests were run which gave fuel consumption figures valid at Ft. Bliss in that terrain. Where several numbers are given, several different courses were run. Secondary and cross country roads were wet and heavy at that time.

	XM1	M60
Paved	.56 mpg	.82mpg
Secondary	.29,.36,.56	.46,.53,.60
Cross Country	.15-.26	.21-.38

Comparative Mission Profile

Fuel Consumption

Based on TRADOC mission profile.

Computed based on DT fuel consumption data for given conditions, i.e., secondary road @ 25 mph.

Probably optimistic due to lack of transients.

Used because it is easy to compute and provides a basis of comparison.

XM1 - VS - 1500 HP DIESEL

1. Fuel consumption for the 1500 horsepower AGT 1500 turbine and AVCR 1360 diesel engines, together with the mission profile upon which the consumption is based, is shown below:

MISSION PROFILE	Distance (Miles)	AVCR 1360 (DT I-58 Tons)	AGT 1500 (DT II-59.8 Tons)
Secondary Road @ 25 MPH	85	.48-.61 MPG**	.56 MPG
Cross Country @ 17 MPH	56.4	.31 MPG	.26 MPG*
Idle for 5.17 Hrs		7.9 Gal/Hr	10.8 Gal/Hr
	141.4	400-362 Gal	425 Gal

*Based on preliminary DT II results. Final results pending completion of DT II. .26 MPG for AGT 1500 is not directly comparable to .31 MPG for AVCR 1360. See below.

**25 MPH was shift point between 3d range converter and lockup. Values shown reflect consumption in lower and higher range.

2. Values shown above reflect turbine engine fuel consumption from 6.3 to 17.4 percent more than that for the equivalent diesel engine over the same mission profile.

3. Data reflected for the diesel engine was determined during DT I on the GM prototype XM1 tank weighing 58 tons. Assuming equal armor protection as the current XM1 tank, the diesel engine would increase the weight of the tank to approximately 60.8 tons. With this increased weight, it is estimated that the fuel consumption of the turbine engine would then range between 1.9 to 12.4 percent more than the equivalent diesel engine for the above mission profile.

4. Previous data used .30 MPG for the AGT 1500 fuel consumption. This figure compared directly to the .31 MPG for the AVCR 1360 diesel engine; both were average figures from DT I endurance running. XM1 used 396 gallons of fuel in this analysis.

This data, used for the same mission profile, gave the following results for the different conditions.

	AGT 1500	AVCR 1360	Fuel Required For Turbine
58 Ton Diesel (DT I as tested)	396 gal	400-362 gal	9.4% more-1% less
59.8 ton diesel (equal weight)	396 gal	413-373 gal	6.2% more-4.3% less
60.8 ton diesel (equal protection)	396 gal	417-378 gal	4.8% more-4.9% less

Comparison with M60 (Rise) Engine

	M60 Rise	XM1
Secondary Road - 85 Miles	.48 MPG (20 MPH)	.56 MPG (25 MPH)
Cross Country - 56.4 Miles	.52 MPG (14.4 MPH)	.26MPG* (17 MPH)
Idle - 5.17 Hours	5.3 gal/hr	10.8 gal/hr
	313 gal	425 gal

*Preliminary DT II data

XM1 uses 36% more fuel than M60 under this profile.

Previous data, using .30 MPG for the cross-country turbine figure, yields 396 gallons for the XM1 and 27% more fuel required.

275 Mile Cruising Range Requirement

Rationale - (General Rogers testimony)

The XM1 fuel consumption requirement is specified in terms of achieving a range of 275 miles when the tank is driven at 25 mph on dry, level, secondary roads. This criterion is based on a mission profile analysis by the Tank Special Study Group in 1975 which indicated that, if the XM1 could achieve 275 miles under the conditions I cited, then it was reasonable to expect that the tank would be capable of sustained operations between refueling every 24 hours. As you can imagine, the actual distance traveled during a twenty-four hour period will vary depending on the operational scenario.

Conduct of Test -

a. 25 mph, straight, level, dry secondary roads.

b. Short distance (1/4 mile) of steady - state operation using calibrated fuel flow meters. Get mile/gallon figure.

c. Use measured vehicle usable fuel capacity (gallons).

d. Compute cruising range - Miles/gallon x gallons = Miles.

Realism of Test -

a. Artificial - doesn't reproduce any operational scenario.

b. Short test, extrapolated data.

c. No steering, which uses power and increases fuel consumption.

Why Used -

a. Set up in MN & Specification.

b. Fairly reproducible.

c. Standard fuel consumption test.

Variables -

a. Road condition (there is no standard secondary road).

b. Vehicle variations.

c. Driver variations.

144 Miles In OT

(Question to General Rogers)

General Rogers Answer:

General Rogers: The figure you cite for the range of the XM1 during OT II, 144 miles, was based on a gross estimate of fuel deliveries to XM1s by fuel trucks lacking metering devices; the time period included the OT II training phase during which the tanks did not operate on a typical mission profile; and finally, during the period covered, one of the tanks experienced a major fuel leak.

This is correct.

The period covered included OT II training.

There was extensive idle during this period and all of OT II which contributes ØMPG.

Overall Comparison

From all sources, a range of fuel consumption figures emerges. For discrete tests, XM1 fuel consumption will probably fall in these ranges:

		Comparison with M60
Paved	.56 - .71 mpg	48% more
Secondary Road	.36 - .56 mpg	11-58% more
Cross Country	.15 - .30 mpg	35-45% more
Idle	8.7 - 10.8 gal/hr	

If pressed for a single planning figure based on overall fuel consumption seen to date under all circumstances, with no control, lots of idle, etc., .35 mpg (2.86 gal/mile) is probably a reasonable number. It is based on a subjective guess.

Appendix C-5

DRCPM-GCM-SM 8 May 1980

COMMENTS ON CHRYSLER'S LETTER
"XM1 TANK OPERATING RANGE"
NTX-12408 dated 25 April 1980

1. In response to a PMO request to propose an equivalent range requirement for paved roads to replace the present 275 mile, 25 MPH secondary road requirement, Chrysler has proposed a 300 mile range calculated at 30 MPH.

2. PMO proposed using paved roads to compute the range requirement because there is no "standard" secondary road and to reduce the variability of results achieved on the same secondary road due to moisture in the soil, etc. Chrysler proposed increasing the speed to 30 MPH to insure that the transmission is in 4th gear lockup. This is reasonable and should improve repeatability of the tests.

3. However, when speed is increased from 25 to 30 MPH, the tank operates more efficiently and will go farther on the same amount of fuel. The DT II fuel consumption test results are listed below:

	25 MPH	30 MPH
Paved Road	.64 MPG	.70 MPG
Secondary Road	.56 MPG	.65 MPG

4. The underlying fact is that the range, under any conditions, should not be decreased. Changing the speed at which the test is run and road surface merely improves repeatability.

5. Based on DT II data at 25 MPH, secondary roads, 492 gallons of fuel are necessary to meet the 275 mile cruising range requirement (275 mi/.56 MPG=492 gal).

6. Using 492 gallons, and based on DT II data, the cruising range on paved roads is: 25 MPH: 492 gallons x .64 MPG = 315 miles. 30 MPH: 492 gallons x .70 MPG = 344 miles.

7. The fuel consumption data in para 3 is based on the lower track tension which is no longer used. Recent tests show a 10% increase in fuel consumption at the higher current track tension. This would decrease the 25 MPH secondary road range from 275 mi to 247.5 miles. Decreasing the paved road range by 10% results in:

25 MPH: 284 miles
30 MPH: 310 miles

8. Recommend that PMO rewrite the System Specification cruising range requirement to be demonstrated on paved road at 30 MPH. The required minimum range should be increased to between 310 and 344 miles. 310 miles on paved roads at 30 MPH corresponds to 247 miles on secondary roads at 25 MPH (higher track tension) and 344 miles on paved roads at 30 MPH corresponds to 275 miles on secondary roads at 25 MPH (lower track tension).

DRCPM-GCM-SM 8 May 1980

9. It is my opinion that, since the higher track tension was a Chrysler decision and required for track retention, Chrysler should not be given any substantial relief from the range requirement and the cruising range should be specified on 340 miles.

Paul M. Root

PAUL M. ROOT
Major, OrdC
Automotive Branch

Appendix C-6

XM1 FUEL ECONOMY

EPA ESTIMATED OPERATIONAL MPG	ESTIMATED SECONDARY ROAD
.28**	.56

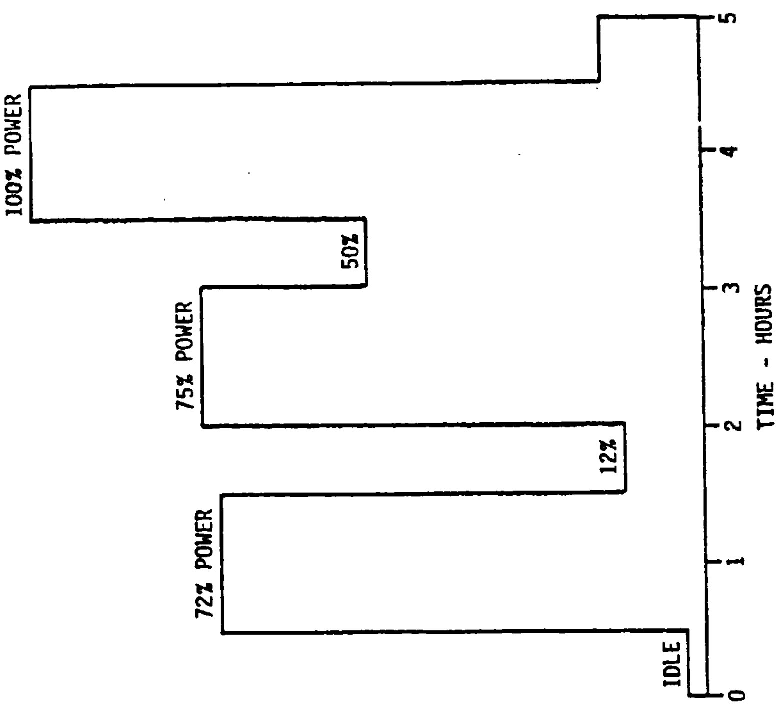
** COMPARE THIS ESTIMATE TO THE ESTIMATED MPG OF OTHER TANKS. YOU MAY GET DIFFERENT MILEAGE DEPENDING ON HOW FAST YOU DRIVE, WEATHER CONDITIONS, TERRAIN CONDITIONS AND ENEMY SITUATION. ACTUAL SECONDARY ROAD MILEAGE WILL PROBABLY BE LESS THAN THE ESTIMATED SECONDARY ROAD FUEL ECONOMY. CALIFORNIA ESTIMATES ARE DIFFERENT.

APPENDIX D

Appendix D-1

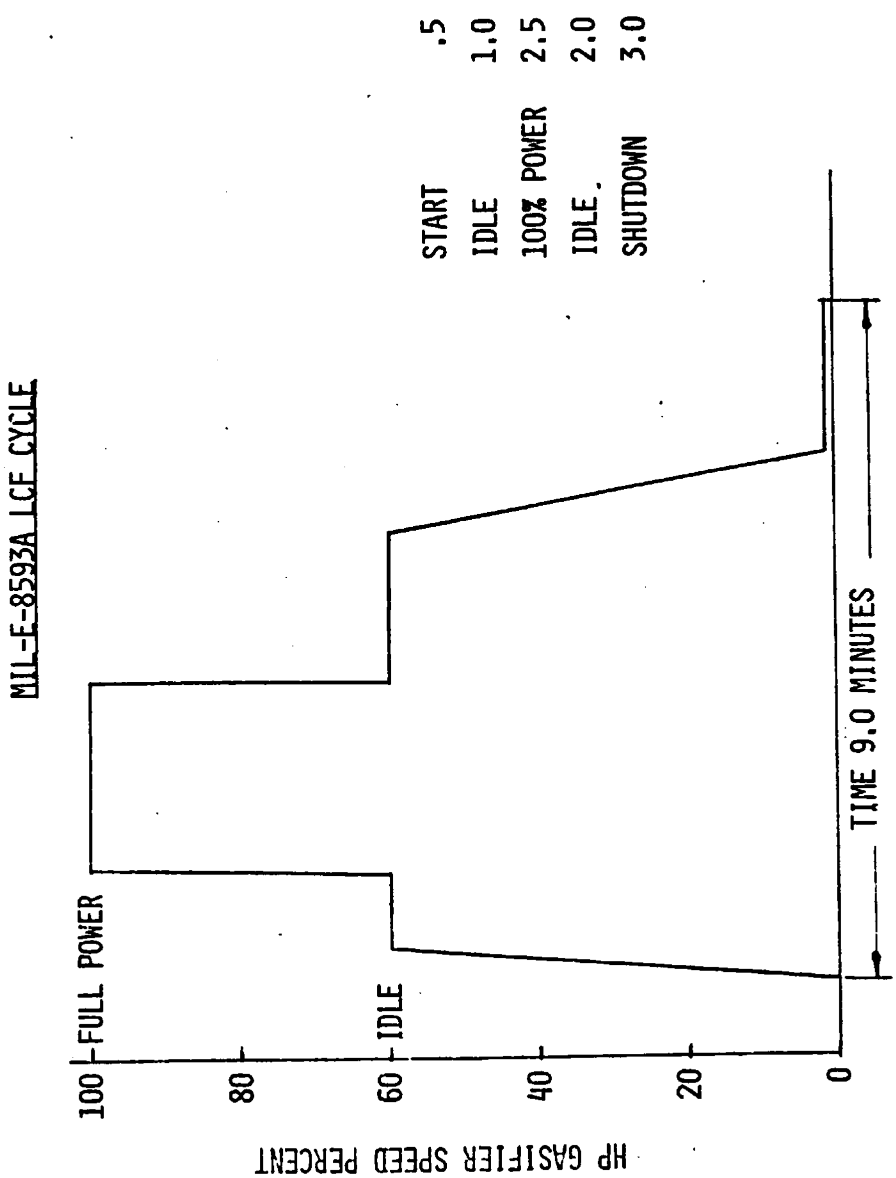
400 HOUR DURABILITY TEST CYCLE

- 80 5 HOUR CYCLES CONSISTING OF:

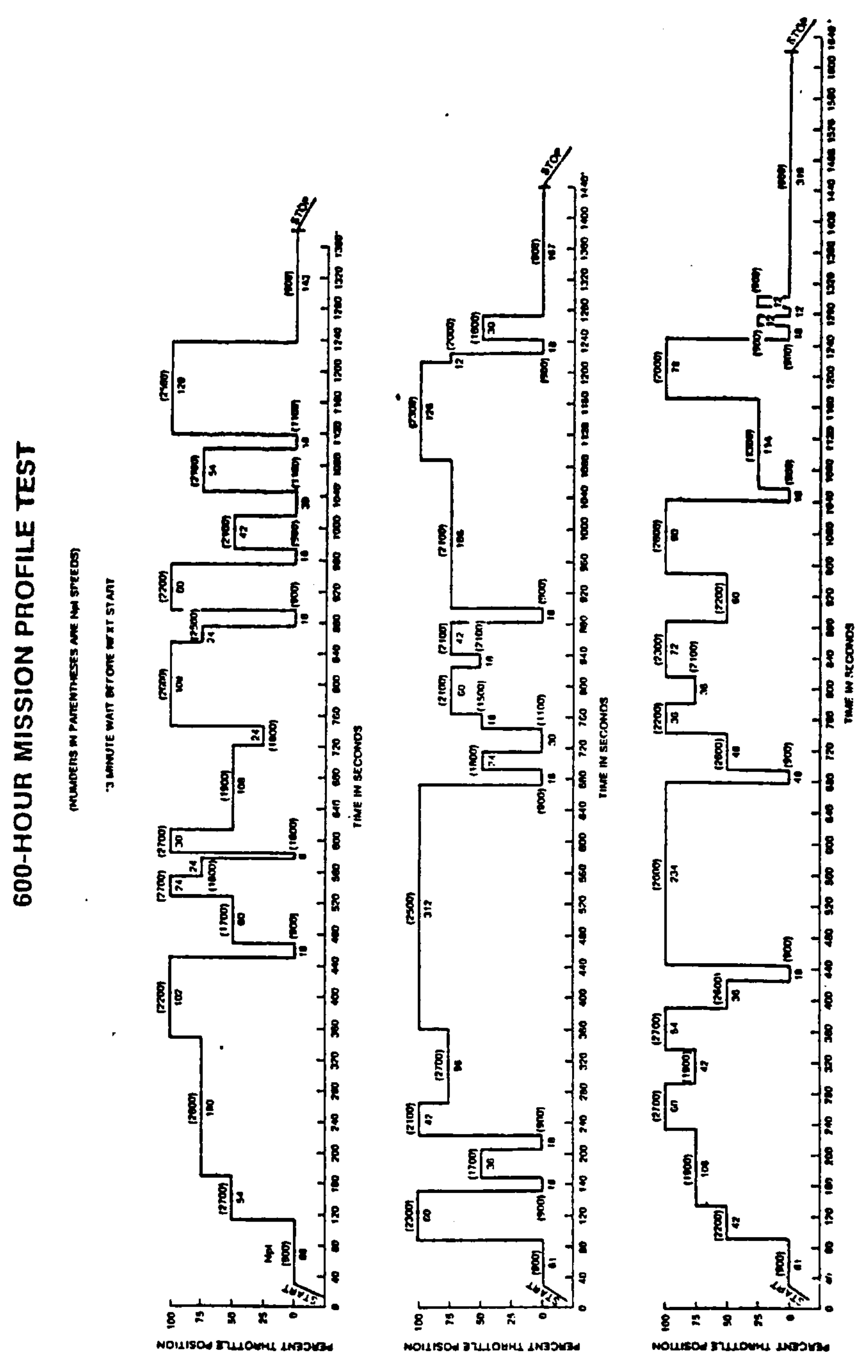


- 40 CYCLES RUN AT 87°F
- 40 CYCLES RUN AT 59°F
- FUEL VVF800 DF-2
  OIL MIL-L-23699
- ENGINE CALIBRATED AT 100 HOUR INTERVALS

Appendix D-2


MIL-E-8593A LCF CYCLE
START .5
IDLE 1.0
100% POWER 2.5
IDLE 2.0
SHUTDOWN 3.0
FULL POWER
IDLE
100
80
60
40
20
0
HP GASIFIER SPEED PERCENT
TIME 9.0 MINUTES

Appendix D-3


600-HOUR MISSION PROFILE TEST
PERCENT THROTTLE POSITION
TIME IN SECONDS
START
STOP

Appendix D-4

INFORMATION PAPER

DRCPM-GCM-SM
10 December 1979

SUBJECT: Engine #53 Test Incident

FACTS.
1. Engine #53, at approximately 672 hours of its 1000 hour test (272 hours into the 600 hour mission profile test) had a test incident 6 December 1979.

2. The engine was inadvertently shut down from full speed and full power by use of the lightning valve. This shut off the fuel flow to the fuel nozzle. At this point, the flame went out due to lack of fuel and the engine was still turning at high speed. Either the lightning valve failed, allowing more fuel into the engine, or the valve was opened by a test engineer who realized his earlier mistake.

3. Fuel was injected into the engine and was blown through the combustor and turbines. It did not ignite because air velocity was too high. When it reached the recuperator, the velocity slowed due to the larger area. The hot recuperator core ignited the air-fuel mixture and may have acted as a flameholder. The rear half of the recuperator on the inside was burned. The recuperator now fails a pressure check, indicating burn-throughs in the plates.

4. This is a <u>test cell incident</u>. It is impossible for a similar failure to occur in a tank due to the fact that once the engine shutdown cycle is started, there is no way to restart the engine or reintroduce fuel until the engine has stopped.

5. Damage appears to be confined to the recuperator core. A substitute recuperator core will be installed in Engine #53 and the test will continue.

MAJ ROOT/31231

Appendix D-5

EGLIN COLD ROOM TEST FOR P8

PROBLEM: Whether to go to Eglin Cold Room as scheduled or delay. Two possible delays: 7-12 days or next test cycle (November).

1. BACKGROUND:

P8 is scheduled for a systems test in Eglin Cold Room at temperatures to -65°F. This is retest due to poor performance of engine starting and fire control at temperatures to -25°F at APG on two tests.

AVCO has been testing Engine #34 in their engine cold room. Tests include alternate fuel nozzles (Excello and Parker-Hanifen) for starting. Problems have been encountered starting at -25°F with vehicle batteries and at -65°F. The engine has excessive oil consumption.

2. ASSUMPTIONS:

a. Engine 34 will not be available (repaired) Friday at Chrysler for installation in P8.

b. No successful lab starts will have been made at -65°F prior to the Eglin test.

c. No suitable DFA fuel will have been obtained prior to the test.

d. Urgency of cold room test has diminished since Arctic test has been postponed one year.

e. Eglin can provide an extra five days.

3. FACTS:

a. Engine #34 currently has high oil consumption. Exact cause is not known. Replacement of reduction gearbox is likely candidate for fix, but not certain fix.

b. Engine has not successfully started at -25^{O}F using cold soaked batteries.

c. No successful starts have been made at -65^{O}F.

d. DFA fuel is not to specification. Cloud point is 10^{O}F too high (-50^{O}F instead of -60^{O}F).

e. Chrysler/AVCO don't know current requirements for starting at -65^{O}F.

f. AVCO has not chosen and sufficiently tested a production configuration nozzle. Two candidates exist, each with minimal testing.

f. Although current cold room test plan calls for using vehicle fuel system (tanks, vehicle pumps, etc) Chrysler had indicated they will not do so. They plan to pump from a drum of fuel, not testing the vehicle system. Problem is draining fuel tanks when fuels must be changed.

h. AVCO cold room currently being repaired. Will not be available for further cold starting until late Wednesday or Thursday.

i. C5A must be cancelled 72 hrs prior to flight time. (NLT COB 20 July.)

j. Test plan has seven days of contingency in it.

4. ALTERNATIVE COURSES OF ACTION:

a. Maintain current schedule - ship 24 July.

b. Slip one week - ship 31 July.

c. Slip until next available test cycle - Nov 79.

5. DISCUSSION OF ALTERNATIVES:

a. Maintain current schedule. This requires shipping P8 on 24 July. It is no longer viable because AVCO has indicated that the engine will not be shipped to Chrysler until 23 July.

b. Slip delivery one week - ship P8 on 31 July.

(1) This allows time to deliver engine provided no further problems occur.

(2) Impacts test schedule at Eglin, but Eglin states that a few days slip on tail end can be tolerated. Therefore, won't lose a full week.

(3) Minimal opportunity for further cold start testing at AVCO prior to shipping engine.

(4) Minimal time to resolve Chrysler/AVCO interface problems concerning starting.

(5) Production nozzle decision won't be validated with lab testing.

(6) No opportunity for getting good DFA prior to test.

(7) Will maintain schedule for test results with high risk.

(8) Will not upset AF or cause loss of funds due to failure to use cold cell

c. Slip until next available window - November 79.

(1) Requires rescheduling test cell.

(2) Provides time for AVCO lab testing of engine in cold cell.

(3) Time to resolve interface problems.

(4) Time to choose and validate production fuel nozzle.

(5) Adequate time to repair engine.

(6) Slips schedule for test results three months. Program/political impact?

(7) Possible opportunity to obtain good DFA.

(8) Provides time to rework Chrysler test plan to provide true systems test.

(9) Lower risk of unsuccessful test.

6. CONCLUSION: The week slip does not provide any great assurance that the engine and interface problems will be solved. The slip until November provides much needed time to prepare for cold room.

7. RECOMMENDATIONS:

a. Postpone Eglin Cold Room Test until November.

b. Direct Chrysler to create Task Force to resolve engineering problems associated with Cold Room Test to assure success.

Appendix D-6

INFORMATION PAPER

ZW Tripp

~~DRCPM-GCM-SM~~
30 November 1979

SUBJECT: Penalty Runs 'on 1000 Hour Engine Components

FACTS.
1. The question of "penalty runs" on the components of Engine #52 which did not complete the full 1000 hour test was raised by Mr. Jack Horan during Admiral Linder's visit to AVCO Lycoming on 28 November 1979. A "penalty run" consists of putting those components in another engine and running to the specified cycle until the full 1000 hours have been completed on those components.

2. It is not the intention of the PM, XM1 Tank System, to conduct "penalty runs" on components from the 1000 hour tests for either the prototype or LRIP engines.

3. There are several reasons for not doing this:

a. The 1000 hour test corresponds to 17,000-21,000 miles of vehicle operation. It is a severe overtest of the engine which has a requirement of 10,000 Mean Miles Between Failure (MMBF). The knowledge to be gained from conducting a "penalty run" under these circumstances does not warrant the use of assets required to support the test.

b. The "qualification" test for the engine, per contract between Chrysler and AVCO Lycoming, is a 400 hour durability test (NATO type cycle). The engine has repeatedly successfully completed this test.

c. The 1000 hour tests were intended by the OSD Panel to be part of an "adequate engine improvement and verification test effort", and not a qualification test. The Panel does not require no parts replacement or "penalty runs" on these tests for either the prototype or LRIP engine tests. In fact, the Panel states that the existing failure rate on engines (in April 79) was not unusually high for a turbine at that stage of development testing and "There will be more such failures and incidents".

d. There are no suitable FSED engine assets now available, or projected to be available, to conduct such "penalty runs". LRIP assets will not be available.

DRCPM-GCM-SM 30 November 1979
SUBJECT: Penalty Runs on 1000 Hour Engine Components

e. The cost of such a test and the time to conduct it, versus the knowledge to be gained, is prohibitive. Est. cost $500-600K, 4 months duration, report available in May.

4. Conversation with Mr. Ralph Tyson, Propulsion and Power Branch, USAVRADCOM, reveals that there is no similar requirement on US Army Aviation engines (T 700, etc).

a. The aviation engine qualification test is a 150 hour qualification test. If a component fails during that test, (a typical engine has a 1500 hour TBO and 5000 hour design life) a so-called "penalty run" would be conducted. It would consist of an abbreviated test designed to stress the particular component which failed.

b. The Army Aviation community does not have long duration qualification tests. 1000 and 1500 hour demonstration (or assurance) tests and 1000 hour shake tests (mission cycle with flight vibrations) are typical of what is conducted, but failures and parts replacements are expected on such tests and their intent is to identify those areas where future design effort should be concentrated. Successful completion of these tests with no parts replacements are not required or expected and engine and aircraft programs are not contingent upon the results of these tests.

c. Overtests beyond the expected time between overhauls (TBO), such as the AGT 1500 is currently undergoing, are seldom, if ever, conducted and are not factors in continuation of the engine/aircraft program.

MAJ Root/31231

HG

APPENDIX E

Appendix E-1

DRCPM-GCM-SM 17 March 1980

MEMORANDUM FOR CHIEF, SYSTEMS ENGINEERING DIVISION
CHIEF, LOGISTICS DIVISION
CHIEF, PROCUREMENT & PRODUCTION DIVISION

SUBJECT: AGT 1500 Engine Depot Spares

1. Reference:

a. LSA List 09H, Provisioning List Category Codes.

b. LSA Record 10H, Support Items List.

c. AVCO Depot Spares List from Contract 3, CLIN 0001.

d. AVCO Depot Spares List from Contract 6, CLIN 0007.

e. AVCO Maint & Depot Spares List (with deletions) dtd 20 Nov 79, part of Chrysler's Dec 79 spare parts submittal.

f. AVCO Maint & Depot Spares List (with deletions) part of Chrysler 7 Feb 80 letter JDW-0681.

g. Chrysler letter NTX-11868 dtd 22 Feb 80, subject: B&P Quotation for 110 Depot Maintenance Spares,

2. This branch has made an independent review of the AGT 1500 engine and has attempted to identify those parts which will be critical for rebuild of engines. These parts are generally fairly expensive and have long lead times for procurement.

3. Based on this review, there are many critical parts which are not currently under contract (references c, d, and e) or planned to be put under contract (reference f). Additionally, some parts previously planned to be procured have been deleted by action of Chrysler and PMO Logistics without review by Chrysler or PMO Engineering (reference g).

4. The result is that some required parts will probably not be available to rebuild failed engines. Using an engine failure rate between the durability rate and the all-inclusive rate reveals that engine/module rebuilds will be required during DT/OT III. Without adequate depot spare parts, there is a possibility that tanks will be without engines for extended periods of time.

5. Inclosure 1 is a list of parts not on order which were identified by this branch as being critical.

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SUBJECT: AGT 1500 Engine Depot Spares

17 March 1980

6. Chrysler may have a plan to use production parts for depot rebuild and then replace the parts with those which are planned to be depot spares but if it exists, this plan needs to be formalized and agreed to by AVCO and PMO.

7. It should be noted that AVCO submitted a Comprehensive Maintenance and Depot Spare Parts proposal to Chrysler in August 1979. PMO did not begin to receive increments of this proposal from Chrysler until December 1979 and the latest submittal is dated 7 February 1980.

8. The critical parts analysis (Inclosure 1) is an independent Automotive Branch assessment. To insure accuracy, the listing must be reviewed with AVCO and Chrysler engineers and logisticians for concurrence, additions and deletions.

9. Recommend the following actions be taken:

a. A PMO/Chrysler/AVCO task force be established to determine exactly which spare parts are critical. PMO Logistics should have the lead in this, but the task force should include engineers and logisticians from PMO, Chrysler and AVCO.

b. The engine depot rebuild plan should be definitized and agreed to by PMO, Chrysler and AVCO. This should include the source of those parts which won't be available from the depot spares.

c. A similar study should be conducted for the transmission.

Paul M. Root
PAUL M. ROOT
Major, OrdC
Automotive Branch

1 Incl
as

CRITICAL PARTS NOT ON ORDER OR PENDING

P/N	Name	Rationale for Necessity
12286195	Rotor Ass'y, LP Comp	One pending. More needed. This part can be damaged
12286191	Shaft, Comp, Low Pressure	Deleted. Need this item. It is part of rotor ass'y above.
12286229	Disc Ass'y. 2 & 3 Stg. LP Comp	Deleted. Need these as they can be damaged due to FOD, etc. Don't want to have to replace entire rotor ass'y for this damage.
12286204	Disc Ass'y 4 & 5 Stg LP Comp	Deleted - Need these - see above reason.
12286183	Disc, Rotor 1 stg	Deleted. 1st stage LP disc is most likely to be damaged by FOD. Need this part.
12286231	Housing ass'y, Low Pressure	Deleted. OK if component parts are spared.
12286232	Housing, Low Pressure	Three on order. May need more. Housing can be damaged by FOD.
12286162	Vane Ass'y stator	Eight on order. Need more. Required if FOD occurs.
12286226	Vane Ass'y stator	Eight on order, Need more. Required if FOD occurs.
12286242	Housing, Intermediate	Deleted - Need this part- damaged if AGB bevel gear and bearing fails. If downed component adequately stocked, can get by without it.
12286160	Housing, #2 bearing seal	Deleted - need this part.
12286235	Housing, Intermed Mach.	Apparently part of Hsg, Inter P/N 12286305 of which four are pending. What is it? More are probably required?
12286931	Brg, Ball, Pos #11	Not on order. These are necessary

CRITICAL PARTS NOT ON ORDER OR PENDING

P/N	Name	Rationale for Necessity
12286253	Vane, Compr.	One on order. Need a lot of these. It is a replaceable component.
12286302	Rotor Ass'y, HP Compr	Deleted. A few as required unless all down components are adequately stocked.
12286279	Compr rotor HP	Deleted - Need several, even if had P/N 12286302 above.
12286303	Impeller, fan, axial	Need these for replacement if damaged by compressor failure, etc.
12286237	Impeller, Compr, HP	Not on order - need it - part of above ass'y which has been deleted.
12286239	Disc, Comp, rotor, 2 stg	Deleted . Need it. It is a part of P/N 12286282 disc ass'y, comp rotor, but you don't want to have to replace the entire ass'y if one disc is damaged.
12286323	Hsg Ass'y, #3 Brg	Deleted - often damaged and need the part.
12286322	Hsg, #3 Brg	Not on order - Part of 12286323 above which is also not on order.
12286331	Plate & Disc, 1st Turbine	Deleted. Need this assembly or all component parts.
12286339	Disc Ass'y, 1st Turbine	Two pending. Need more. Component parts disc and plate not on order.
12286398	Collector, Housing	Not on order. Need several of these. Don't know if component parts are on order.
12286450	Air diffuser, turbine	Deleted. Need it or component parts.

CRITICAL PARTS NOT ON ORDER OR PENDING

P/N	Name	Rationale for Necessity
12286451	Hsg Ass'y, #4 Brg	Deleted. Need it. Often replaced if damage occurs to HP comp.
12286452	Hsg Ass'y rear, #4 Brg	Pending - 2. Need more - see above.
12286458	Liner E Cover Ass'y	Not on order - critical.
12286384	Liner, Combustor	Not on order - critical part. Is the P/N correct? Possible new P/N 12286890.
12286650	IGV Bleed Actuator	Not on order. Need this part - critical.
12286312	Valve Ass'y, Air Bleed	Not on order. Part of above. Critical part.
12286306	Hsg Value	Deleted. Part of 12286312, also not on order. Need it.
12286004	Rear Eng. Sub-Ass/y	Not on order. Need it on major down components.
12286467	Power Turbine Ass'y	Not on order. Need it or critical down parts.
12286354	Rotor & Shaft	Not on order - Need it or parts.
12286329	Shaft, Shouldered	Not on order. Part of rotor and shaft above.
12286363	Rotor, Engine	Not on order - critical part? Possibly old part #.
12286328	Rotor, 2d stg mach	Not on order - part of above. Old cast P/N?
12286362	Nozzle, Turbine, Turb	Not on order. Critical. Possibly old P/N.
12286348	Nozzle, 2d Stg	Not on order. Part of above. Critical. Possibly old P/N.

CRITICAL PARTS NOT ON ORDER OR PENDING

P/N	Name	Rationale for Necessity
12286889	Seal Ass'y, LP Nozzle	Not on order. Critical. Possibly old P/N.
12286482	Hsg Ass'y, #5 Brg	Not on order. Critical - Old P/N?
12286569	Hsg Ass'y, #5 Brg	Not on order. Part of above. Old P/N?
12286546	Case & Vane Ass'y	Not on order. Critical. Down parts not on order either.
12286565	Hsg Ass'y, #5	Not on order. Need it.
12286515	Hsg, #5	Not on order. Part of above. May need it.
12286567	Seal and Diaphragm Ass'y	Not on order. Need it or down parts.
12286521	Bracket, Piston, Nozzle	Deleted. This had been deleted since it was a part of the rear engine module. It is reauired since rear module is not replaced for a bracket failure.
12286560	Bracket Support	Deleted. Same reason as above. Needed.
12286735	Regenerator Ass'y	Seven pending. Price in proposal is $35.00. Too cheap. Wrong P/N?
12286774	Matrix Ass'y Regenerator	Deleted. May need these.
12286039	Gear Box, Reduction	Deleted. May need some ass'ys.
12286013	Hsg, Red Gear Box	Not on order. Need at least one. Part of above.
12286122	Case and Cover Ass'y	Deleted. Need some. Critical down parts not on order
12286082	Hsg, Mechanical	Not on order. Part of above.

CRITICAL PARTS NOT ON ORDER OR PENDING

P/N	Name	Rationale for Necessity
12286137	Cover, Mechanical Dr	Not on order. Part of above.
12286933	Cable Ass'y IGV FOBK	Not on order. Need these. Different P/N?

APPENDIX F

Appendix F-1

DRCPM-GCM-SM

FACT SHEET

Automotive Branch
MAJ Root/mj/31231
23 January 1978

SUBJECT: Diesel Engine Back-Up Program for XM1

Project Manager, XM1 Tank System

PURPOSE. To provide information on back-up diesel engine proposals for the XM1.

BACKGROUND.

1. In the Spring of 1977 the House Armed Services Committee recommended approximiately $10M funding for a "back-up diesel program". The Senate did not support such a measure, and no funds were included in the Appropriations Bill for this project.

2. In 1977 TCM submitted an unsolicited proposal to TARADCOM for continued development of the AVCR 1360 diesel engine. The program's objectives included completion of the advanced diesel technology development of the engine (primarily Variable Area Turbochargers and Variable Speed Cooling Fans) and accomplishment of the configuration changes necessary for installation of the engine into the XM1 Tank. No fund requirements were included in the proposal. The proposal was reviewed by the Automotive Branch which concluded that the advanced technology aspect of the proposal was good, but there were many objections to considering it as a "back-up engine" for the XM1.

3. On 21 November 1977 Senator McClellan, Chairman of the Senate Appropriations Committee sent a letter to the Secretary of Defense Brown stating that the Committee believed it necessary to consider a diesel back-up engine for the XM1 Tank Program. Secretary Brown's reply stated that "While all information leads us to believe that there is no need for a diesel engine back-up program for the XM1 Tank, the door is not closed."

FACTS.

1. The success to date of the turbine engine has been such that there is no need for a back-up diesel engine for the XM1. In addition to successfully meeting all performance requirements, the turbine engine completed back-to-back 400 hour NATO endurance tests. Last Fall a third 400 hour NATO endurance test was successfully completed with a Validation Phase engine updated to FSED configuration.. The turbine

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SUBJECT: Diesel Engine Back-Up Program for XM1

engine's durability is above the predicted growth curve and is currently at 6400 MMBR. The only unresolved durability incident to date is the failure of a high pressure compressor stage resulting from a surge condition believed to be caused by a faulty fuel system or bleed valve operation. During the total development program the engine will achieve over 29,700 hours and 120,800 miles of testing. The engine should fully meet all operational requirements at the conclusion of this program, and a back-up diesel program would have many more risks than the current turbine program.

2. Neither the $10 million funding level proposed in the HASC nor the scope of the November TCM proposal would result in "back-up diesel engines for the XM1". The low funding level and the proposed scope of work are both indicative of a relatively low-level advanced technology development program with limited objectives. A program of this nature could result in advanced technology which might be applied to improve the performance of other diesel engines, but would not result in a back-up diesel engine which could be incorporated into the XM1 without excessive program delays.

3. A true diesel back-up program, which would allow incorporation of the diesel engine into the XM1 without undue program delay, should that become necessary, would be a massive and expensive undertaking. Such a program would include:

a. Procurement of engines, transmissions, and associated power train components. A one-year lead time on this procurement is expected.

b. Development and test of the advanced technology engine components mentioned above (Variable Area Turbochargers and Variable Speed Cooling Fans).

c. Extensive testing (engine) in the laboratory and in vehicles. Existing vehicles must be modified or new vehicles built to support the testing. Testing could not start until the hardware was procured.

d. Vehicle integration planning to modify the XM1 production vehicles for the diesel engine. Extensive engine compartment redesign can be anticipated.

e. Long lead procurement for production for certain engine components and certain of those other components of the vehicle which must be changed to incorporate the diesel engine. New fuel tanks, cooling systems, air intake and exhaust, and vehicle interface connections can be expected.

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f. Facilitization for production. This must be undertaken immediately to procure the machines, etc., necessary for diesel engine production.

g. Production Engineering planning.

h. Major logistics effort. Manuals must be revised for the diesel engine, spare parts procured, mechanics and operators must be trained, etc.

4. The cost of such a true back-up program would probably exceed the cost of the present turbine engine program. A TARADCOM estimate of the cost is $31.9 million excluding engine software and vehicle costs.

5. Even with a major effort, it is doubtful if the diesel engine could be ready for production in time to meet the XM1 delivery schedule. A program slip must be anticipated if the diesel engine were to be incorporated.

6. This Fact Sheet does not require coordination.

E. W. TRAPP
Chief, Systems Engineering Division

PROJECT MANAGER ACTION:

NOTED:______________

SEE ME:______________

Appendix F-2

DRCPM-GCM-SM

INFORMATION PAPER

Automotive Branch
MAJ Root/31231
25 April 1979

SUBJECT: Backup Engine Program

PURPOSE: To provide the implications of developing backup diesel and turbine engines for the XM1.

1. **Diesel Engine.**

a. Assumptions:

(1) AVCR 1360 1500 HP diesel engine is used.

(2) Additional development is limited to variable area turbochargers, variable speed cooling fans and necessary vehicle redesign.

(3) User accepts one ton weight penalty of diesel engine to preclude vehicle redesign.

b. Implications:

(1) Time:
- 5 year program from contract to beginning of LRIP.
- 3-1/2 years to LRIP DSARC decision.
- 3-1/2 years of facilitization.
- 1 year DT/OT.

(2) Resources:
- 17 new engines.
- Engine rebuilds.
- 12 new transmissions.
- 10 Pilot Vehicles for DT/OT.
- US Army troop unit for OT.

(3) Funding:

$144.8M - for engine design, build, vehicle build, testing and ILS.
$ 85M - for facilitization.
$229.8M - Total to start of LRIP.

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SUBJECT: Backup Engine Program

25 April 1979

2. Turbine Engine.

a. Assumptions:

(1) New turbine developed by a different contractor.

(2) Government accepts some risk in concurrency of development and testing.

b. Implications:

(1) Time:
- 9-1/2 year program from contract to start of LRIP.
- 4-1/2 years initial development and test.
- 5 years vehicle integration, testing and engine qualification.
- 8-1/2 years to LRIP DSARC decision.
- 3-1/2 years facilitization.
- 1-3/4 year DT/OT.

(2) Resources:
- 30 new engines.
- Engine rebuilds.
- 12 transmissions.
- 10 Pilot Vehicles for DT/OT.
- US Army troop unit for OT.

(3) Funding:

$255M - engine design, development, test, pilot vehicle build, vehicle test, ILS.
$ 80M - facilitization.
$335M - Total to start of LRIP.

3. There is no assurance that the engine developed under either of the above programs will [redacted] be more reliable or durable at the end of its development program than the AGT 1500 engine now is.

Appendix F-3

Automotive Branch
MAJ Root/31231
1 August 1977

FACT SHEET

DRCPM-GCM-SM

SUBJECT: Use of T700 Engine in XM1 Tank

Project Manager, XM1 Tank System

PURPOSE. To inform the Project Manager of the impracticality of using the T700 engine in the XM1 Tank.

FACTS.
1. The AGT 1500 turbine engine was designed as a tank engine, and as such, was configured to fit in a tank engine compartment to interface with the rear mounted transmission and to operate in a ground vehicle environment. The T700 engine was designed as an aircraft engine with its constraints and for its particular environment.

2. Significant differences between the two engines are listed:

Characteristic	AGT 1500	T700
Power (Continuous)	1500 HP	1250 HP
Weight	2300 lbs.	415 lbs.
Compressor Materials	Steel	Titanium
Housings	Steel Castings	Fabricated Sheet Metal
Air Cleaning System	External	Integral inlet particle separator
Recuperator	Yes	No
Lube System	External	Self-contained
Combustor	Single can	Annular
Fuels	DF2, DF1, JP4 JP5, DF-A	JP4, JP5
Reduction Gearbox	Integral	External
Alternator	External	Integral
Peculiar Accessories	None	Anti-icing valve History recorder Magnetic chip detector

3. It would be theoretically possible to use the T700 engine in place of the AGT 1500 although a tremendous amount of development and redesign work would be required to make an engine designed for an aircraft environment suitable in a ground vehicle environment. The major areas requiring development or redesign, and other major problem areas, are listed below:

a. The drive shaft for the T700 engine exits the front of the engine and no reduction gearbox is provided. A reduction gearbox would be required to reduce the engine output speed from 21,000 RPM to 3,000 RPM for interface with the transmission. Also, it would probably be desirable to convert the engine to a rear drive configuration and avoid the problem of having the exhaust in the vicinity of the bustle ammo stowage.

b. The T700 does not incorporate a recuperator to recover exhaust energy under part load conditions to improve fuel economy. A quick estimate of the additional fuel required on an overall basis for a non-recuperative turbine vs. a recuperative turbine is in the area of 30-40 percent. If this penalty is not acceptable, a recuperator system would have to be developed for the T-700.

c. The T-700 is designed to operate on the standard aircraft fuels, JP-4, and JP-5. In order to be compatible with the logistical system for the other ground combat vehicles additional development would be required to allow for operation on DF-2 fuel.

d. The T700 engine has a continuous power rating of 1250 HP at sea level and 85°F while the AGT 1500 is rated at 1500 HP. The 250 HP reduction would reduce vehicle performance accordingly.

e. The T700 engine incorporates an integral particle separator on the front of the engine. For ground operation it is felt that, as a minimum, some form of additional filtration would be required. It is probable that the engine would have to be redesigned to eliminate the separator and utilize an air cleaner system very similar to that currently used with the AGT 1500. It should be noted that the inlet restriction with clean barrier filters of the Chrysler XM1 air induction system (18 in of H_2O) exceeds the limits of the T700 engine specification.

f. The T700 engine does not incorporate accessory pads of the capacity necessary to drive the vehicle hydraulic pump. The hydraulic pump would have to be relocated to the transmission, necessitating transmission redesign.

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SUBJECT: Use of T700 Engine in XM1 Tank

1 August 1977

g. The current starting system for the T700 is an air turbine which is supplied with air by the helicopter auxiliary power unit. The starting system of the T700 would have to be converted to electric.

h. Combat vehicles are required to operate in up to 125°F ambient temperatures. The temperature rise in the air inlet system for the Chrysler XM1 is 7° to 10°F which results in an inlet air temperature to the turbine of 135°F. This temperature exceeds the specified operating envelope for the T700.

4. The 10 year average DTC of the AGT 1500 is estimated at $110,479. A comparable estimate (Source: AVSCOM) for the T700 is $178,000.

CONCLUSIONS.
5. The extent of redesign of the T700 required to make it an effective tank engine is such that the engine would be, in effect, a totally new engine with very little commonality, except the rotating parts, with the current T700. The cost would probably be higher than for the AGT 1500.

Appendix F-4

Root

XMI

COMPARISON OF AGT 1500 TURBINE ENGINE WITH T700 TURBINE ENGINE

XMI

BRIEFING OUTLINE

MISSION REQUIREMENTS

ENGINE DESCRIPTION

CHARACTERISTICS COMPARISON

MODIFICATIONS

XMI

AGT-1500 PROGRAM SUMMARY

OCTOBER 1965	COMPETITIVE CONTRACT AWARDED
1967	ENGINE AND VEHICLE TESTING BEGINS
1970	INITIAL 400 HOUR NATO TEST COMPLETED
1973	CHRYSLER XM1 PROGRAM INITIATED
1975/76	BACK TO BACK 400 HOUR NATO TESTS COMPLETED
1976	ABERDEEN EVALUATION COMPLETED
1976	XM1 FULL SCALE ENGINEERING PHASE INITIATED
1980	INITIAL VEHICLE ROLL-OFF

XMI

AGT 1500 FSED STATUS

20 NEW FSED ENGINES BUILT

8 VALIDATION ENGINES UPDATED

FSED TESTING

	CURRENT (22 SEP)	FSED TOTALS
LAB	3741 HOURS	8550 HOURS
VEHICLE	23,043 MILES	97,700 MILES

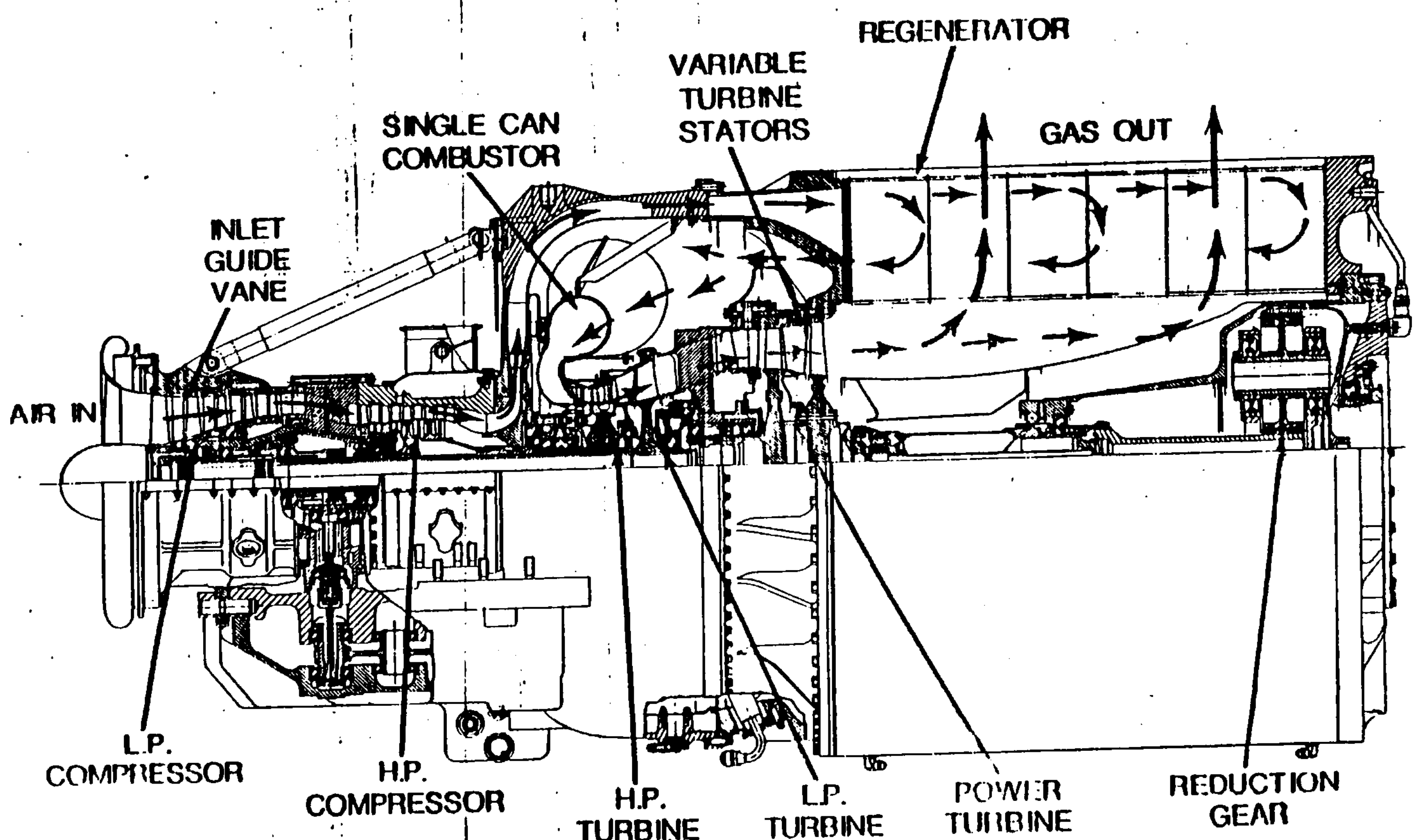
MISSION REQUIREMENTS

REQUIREMENT	GROUND	AIRCRAFT
WEIGHT	NON CRITICAL	CRITICAL
VOLUME	NON CRITICAL	CRITICAL
SPECIFICATION	COMMERCIAL STANDARDS	AIRCRAFT STANDARDS
ACCESSORIES	HIGH POWER - FEW	LOW POWER - MANY
OUTPUT POWER	VARIES CONTINUOUSLY 0-MAX. POWER	FAIRLY CONSTANT
FUEL	COMPATIBLE WITH OTHER GROUND VEHICLES	COMPATIBLE WITH OTHER AIRCRAFT
NOISE	CRITICAL	NON CRITICAL
LOCATION	RELATIVELY INACCESSIBLE	ACCESSIBLE

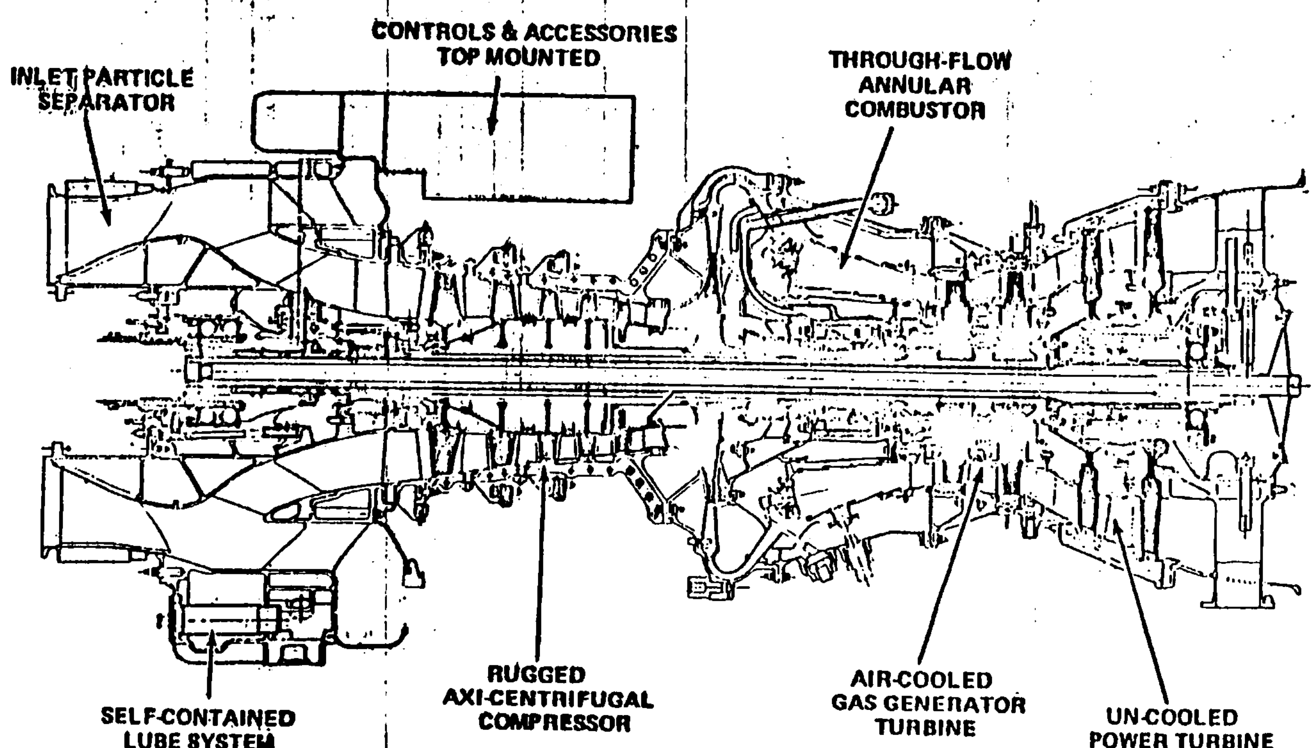
ENVIRONMENT

REQUIREMENT	GROUND	AIRCRAFT
AIR FILTRATION	EXTENSIVE	MINIMAL
ICE	NO ANTI-ICE	ANTI-ICE

AGT 1500C ENGINE SCHEMATIC



T700 Design


CONTROLS & ACCESSORIES
TOP MOUNTED
INLET PARTICLE
SEPARATOR
THROUGH-FLOW
ANNULAR
COMBUSTOR
SELF-CONTAINED
LUBE SYSTEM
RUGGED
AXI-CENTRIFUGAL
COMPRESSOR
AIR-COOLED
GAS GENERATOR
TURBINE
UN-COOLED
POWER TURBINE

XMI

TURBINE ENGINE COMPARISONS

CHARACTERISTIC	AGT 1500	T700	REMARKS
POWER (CONTINUOUS)	1500 HP	1251 HP	DESIGN
WEIGHT	2500 LB.	415 LB.	CRITICAL FOR AIRCRAF
VOLUME	45 $FT.^3$	≈15 $FT.^3$	CRITICAL FOR AIRCRAF
SPECIFICATIONS	COMMERCIAL	AVIATION	SAFETY
CONFIGURATION	MODULAR (3)	MODULAR (4)	MAINTAINABILITY
TURBINE INLET TEMPERATURE	2180°F	HIGHER	
COMPRESSOR MATERIALS	STEEL	STEEL	
HOUSINGS	STEEL CASTINGS	TITANIUM CASTINGS	WEIGHT
AIR CLEANING	EXTERNAL	INTEGRAL INLET PARTICLE SEPARATOR	ENVIRONMENT

XMI

TURBINE ENGINE COMPARISONS (CONTINUED)

CHARACTERISTIC	AGT 1500	T700	REMARKS
RECUPERATOR	YES	NO	MISSION
LUBE SYSTEM	EXTERNAL	SELF-CONTAINED	WEIGHT AND VOLUME
COMBUSTOR	SINGLE CAN	ANNULAR	MAINTAINABILITY **ACCESSIBILITY**
FUELS	DF1, DF2, DFA JP4, JP5 GASOLINE (EMERGENCY)	JP4, JP5	COMPATIBILITY W/ LOGISTIC SYSTEM
REDUCTION GEARBOX	INTERNAL	EXTERNAL	
ALTERNATOR	EXTERNAL	INTEGRAL	POWER REQUIREMENTS
ACCESSORY GEARBOX	SIMPLE CAST HOUSING **STEEL GEARS**	PRECISION HOUSINGS AND GEARS	WEIGHT
FUEL CONTROL	ELECTRONIC	HYDROMECHANICAL WITH SUPERVISORY	

XMI

TURBINE ENGINE COMPARISONS (CONTINUED)

CHARACTERISTIC	AGT 1500	T700	REMARKS
TORQUEMETER	NOT REQUIRED	REQUIRED	FLIGHT CONTROLS
POWER MANAGEMENT	NOT REQUIRED	REQUIRED	FLIGHT CONTROLS
VARIABLE POWER TURBINE STATOR	REQUIRED	NOT REQUIRED	PART LOAD EFFICIENCY

XMI

MODIFICATIONS REQUIRED IF T 700 WERE TO BE USED IN XM1

INCREASED POWER	PERFORMANCE
VARIABLE POWER TURBINE STATORS	RESPONSE FUEL ECONOMY
RECUPERATOR	FUEL ECONOMY
COMBUSTOR	FUEL COMPATIBILITY
REAR POWER OUTPUT SHAFT	TRANSMISSION INTERFACE
REDUCTION GEARBOX	TRANSMISSION COMPATIBILIT
EXHAUST	VEHICLE COMPATIBILITY
ACCESSORY DRIVES	VEHICLE COMPATIBILITY
STARTER	VEHICLE COMPATIBILITY
ENGINE HOUSINGS	FORDING ENGINE MOUNTING

APPENDIX G

Appendix G-1

DRCPM-GCM-SM

3 November 1977

MEMORANDUM FOR RECORD

SUBJECT: Trip Report

1. On 5-13 Oct 77 the undersigned traveled to England and Germany to talk with PM, MBT 80, BNLO, and visit MaK to observe progress in installation of the AGT-1500/X-1100 power pack in a Leo 2 automotive test rig.

2. On 7 Oct 77 I paid a courtesy call to the US Standardization Group, London, and I discussed the purpose of my visit to MOD, UK. In the course of discussions, LTC Massey requested a copy of the "Deane Memorandum". He also requested information copies of the cover letters of all correspondence with the UK in order that they might know what has been transmitted should he be asked by MOD, UK.

3. I then visited COL Stopford, PM, MBT 80, at St. Christopher House, and MAJ Mike Barneby, and Mr. John Couzzens of his staff. Several items were discussed:

a. COL Stopford expressed the UK's interest in the turbine power package as one of the possibilities for the power pack for MBT 80. He stated that the gun decision might have a bearing on a power package choice.

b. He requested an organizational chart of DARCOM, the PMO, Chrysler, and AVCO, so that he could identify personnel and positions with whom he must deal.

c. He was pleased that the answers to the Rolls Royce questions would be delivered in the immediate future and understood why the production questions could not be answered at this time.

d. Detailed discussions of the questions and answers were held with MAJ Barneby and Mr. Couzzens. Mr. Couzzens was about to travel to the PMO with the ROF group and the knowledge of the nature of the answers helped him prepare for his trip.

e. Clarification of the terminology in some questions was made.

f. In the Rolls Royce questions, there were no questions directed at Allison, only AVCO and Chrysler. COL Stopford stated that he felt RR was only interested in producing the engine and had visited Allison during their trip only because they had been asked to by the UK MOD.

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SUBJECT: Trip Report

4. On 10 Oct 77, in Bonn, I visited LTC Mehrtens of the BNLO. Several topics were discussed:

a. The contents and nature of the weekly reports on the turbine power pack.

b. Contact between the Chrysler tech rep and BNLO.

c. LTC Mehrtens felt that it is important to invite the Germans to observe some specific tests of the turbine before the gun decision is made. If the Germans are invited to observe specific tests (i.e. acceleration, fuel consumption, or braking during EDT-C, and lab tests) and do not accept, he feels it would show lack of a true interest in the turbine. This invitation could be presented at the Executive Group Meeting.

d. LTC Mehrtens requested some turbine fuel consumption data, which will be provided him while he is at PMO.

5. On 11 and 12 Oct 77 I visited MaK, Kiel, accompanied by MAJ Benson and SSG Tocker from BNLO. The visit was highly successful and extremely worthwhile. Discussions of the test plan, schedule, and problems, and an inspection of the installation were held 11 Oct 77. A plant tour and further discussions were held on 12 Oct 77 and minutes were signed. The following people were involved in addition to PMO personnel (Organization charts attached):

Herr Achim Wilczek, Dir of Special Projects, MaK
Dr. Muller, Head of Tracked Vehicle Tests, MaK
Herr Schmitt, Dir of Vehicle Tests, MaK
Herr Olof Lenz, Assistant to Wilcyek, MaK
Herr Sombrowski, Dir of Research Group III, MaK (Installation Design)
Dr. Link, Dir of Power Trains, MaK
Mr. George Psaros, Chrysler Tech Rep

6. MaK appears to be a prosperous company with about 3000 workers. They manufacture large diesel engines for power stations, locomotive, and marine use. They manufacture locomotives, and have a considerable military vehicle business. They manufacture the FRG tracked recovery vehicle, LEO I, are modifying FRG M113's for a diesel engine, and will produce 45% of the LEO II total quantity. They are doing some experimental development work on new tracked vehicles.

7. Mr. Psaros, Chrysler Tech Rep, had been at MaK since 6 Oct 77. He is a great help to MaK in the installation, and is able to answer many questions immediately. He is in daily contact with Chrysler and, so, is able to quickly obtain answers to questions that require expertise at Chrysler.

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SUBJECT: Trip Report

MaK cannot contact Chrysler directly, so he is invaluable in this respect. He should be delegated authority by Chrysler, if he does not already have it, to allow minor installation changes in the power pack, if in his opinion, they do not violate the loan agreement or harm the power pack.

8. The test schedule and tech rep schedule were discussed. MaK has to finalize the schedule with BWB, and a copy of schedules will be delivered to the US at the Executive Group meeting. The most significant feature is that MaK desires to run the test until the end of May and the power pack will not be ready for return until the end of June. (MaK states that the US was informed of this at the last Working Group meeting.) This extension should be acceptable to the US and not affect the program. Currently, no immediate further use is planned for that power pack. This schedule does eliminate the option of rebuilding the FRG power pack for the P11 vulnerability trials and the possible provision of an FSED power pack to Germany. It must be insured that the technical support required for the revised schedule falls within the 19 man-months which were negotiated.

9. The draft test plan, dated 9 Jun 77 and already provided to PMO, was discussed in detail. A detailed test plan will be provided PMO through BWB when available (US should ask for it at the Executive Group Meeting.).

10. The power pack will be:

a. Ground hopped for check out.

b. Tested in the test rig in an environmental chamber equipped with dynamometers for each output.

c. Tested in the test rig at MaK and at a Bundeswehr test track 30 Km from Kiel.

11. Points discussed on the test plan include:

a. MaK desires to install thermocouples inside the transmission at the point of highest temperature of the oil for measurements during the braking tests. Since this may involve opening the transmission, PMO permission must be obtained. Additionally, Allison should provide the location of the highest temperature.

b. Test results can be provided through BWB if requested by PMO (this should be done at the Executive Group Meeting and include periodic reports and interim results as well as the final report).

c. Some data, provided by PMO, has never reached MaK and is needed before tests can begin (details are later).

d. Brake testing would be comparable to BWB tests.

e. Fire suppression system data was requested.

f. Certain tests will be deleted from the draft test plan:

(1) Electrical system tests

(2) Rolling resistance tests

(3) Tests of the shift impulses to the final drive and suspension.

(4) Cross-country travel - due to the hull modifications

12. The following information was requested by MaK. Some of it has previously been provided by PMO but apparently did not reach MaK (Suspicions are that it is at BWB and has not been forwarded).

a. Engine #32 acceptance data.

b. Cooling fan maps.

c. Transmission loss diagram.

d. Accessory losses (power required).

e. Data on the fire extinguisher system to include quantity of Halon and location of nozzles in the engine compartment.

f. Steering radii in each gear.

13. The turbine installation was viewed. MaK has nearly finished the mechanical installation of the power pack in the hull of Prototype #2 of LEO II. It is a thoroughly professional installation. The LEO II hull was modified by lengthening the rear (the rear grille does not open), moving the engine compartment bulkhead forward approximately 8", cutting out and lowering the hull floor 1.5" to provide transmission clearance, cutting away a torsion bar cover, insulating a fuel tank, and minor machining. (Drawings and photos will be provided the US at the Executive Group Meeting.) The modifications are relatively simple and are easily feasible for production or retrofit.

14. The power pack rests on the front engine mounting shoe and the LEO II transmission saddles. An adapter has been made to clamp around the transmission to sit in the existing mounting saddle without modifications. MaK fabricated their own engine mounting shoe from Chrysler drawings. This was

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necessary to interface with the vehicle and allow for the different engine installation angle necessitated by the permanently closed rear grilles. MaK built their own engine mounting sling from Chrysler drawings.

15. Power pack installation was demonstrated and took less than ten minutes (no electrical, etc., hookups were made). The pack is at a similar angle to the US installation and is lowered almost straight down into the engine compartment. The front mount engages the shoe, and as the rear of the pack is lowered, the front cable is shortened with a hand ratchet on the cable, so that the angle of the power pack decreases, and the transmission mounting adapters seat directly on the saddle mounts. Bolts extend through the hull bottom into the transmission mounting adapters.

16. Clearances are tight around the coolers, but there is a great deal of room around the engine. Fuel tanks could be installed on both sides of the recuperator, under the air cleaner, and in a space on the right side of the engine (looking forward) approximately 5'x 3' x 1.5'.

17. Extremely few engine modifications were necessary:

a. A rib on the accessory gearbox was machined down (discussed at last Working Group Meeting).

b. Oil cooler seals and flanges on the outside edges were removed due to clearances.

c. The transmission mounting adapters were clamped around the transmission outputs.

d. Attachments to the turbine for thermocouples, fire wire, etc.

e. An adapter to connect the GE final drives to the transmission is required. MaK desires permission to remove the bolt in the transmission output shafts to connect the adapter. This installation offers possibilities for harmonization. This will be checked with Chrysler.

18. MaK requested three meters exhaust duct seal for their installation as soon as possible (approximately 1 1/2" diameter).

19. Electrical boxes are installed in the hull. Certain connectors were not delivered, and while they are not halting the installation, they are needed very soon. Chrysler is attempting to obtain them.

20. MaK requested US agreement, in writing, for the following:

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a. To remove the bolt in the transmission output shaft to install the final drive adapter.

b. To install a fail-safe fuel shut off between the fuel control and combustor so that fuel flow can be immediately terminated if there should be any problem.

c. The MaK fabricated engine mounting shoe, which has no alignment grooves but only has 0.5 MM of sideplay, is satisfactory.

d. To conduct a single full speed braking run prior to the other driving tests to insure adequate braking.

e. The extended test schedule.

f. Transmission oil thermocouples for the brake tests.

21. MaK appeared concerned with discrepancies found between the manuals provided and the power pack. It was explained that the manuals were current as of early 1976 and same changes had been made in the power pack and not reflected in any manuals. MaK's concern centered around possible damage to the power pack due to following outdated procedures in the manuals. Mr. Psaros is providing updating and clarification of the manuals and contacting Chrysler if he does not have the information at hand.

22. During the plant tour, the LEO I hull machining line was visited. Capability is over 30/month on a 1/8/5 schedule. One machine can turn the hull on its side for turret ring machining. All are reprogrammable for various vehicles. Capacity is also over 30/month for the tracked recovery vehicle.

23. Herr Wilczek showed an experimental "Casemate" tank consisting of an FMBT 70 hull and suspension with two 105mm guns (another version has two 120mm guns) mounted at the front edge of the vehicle. They are adjustable in elevation and have automatic loaders. Azimuth is controlled by the tracks. Crew is three. The fire control system gives the capability of sighting on a target not on the vehicle axis and "swinging through" the target. The gun is stabilized and fires at the instant of proper gun target positioning. This fire on the move capability is controlled either by the driver who swings through the target or the fire control system, which automatically lines up the vehicle with the target and then zig-zags along the axis, firing at the proper times. MaK claims excellent hit probabilities with a vehicle speed of 40 KPH @ 1500M for the 105mm version. The 120mm version was viewed very briefly. I have a photo of the 105mm version firing. Further information should be obtained.

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24. MaK is using German final drives and will return the US final drives.

25. MaK has set up an office for conceptual studies of LEO III.

26. Minutes were signed at the end of the meeting. A copy will be available when translated.

27. I was highly impressed by MaK and the people working on the power pack test. They are highly competent, excellent engineers, and seem dedicated to a successful test. They are somewhat limited in their actions by BWB and it appears that this will be the source of any problems.

28. I returned to the US 13 Oct 77.

/s/ Paul M. Root
PAUL M. ROOT
MAJ, OrdC,

1 Incl
as

Appendix G-2

DRCPM-GCM-SM 4 January 1979

MEMORANDUM FOR RECORD:

SUBJECT: Trip Report to UK 19-20 December 1978

1. On 19 and 20 December 1978 I participated in turbine power pack licensing discussions with the Project Manager MBT80 for the UK. The British are interested in the turbine power pack as a possible option for their MBT80. The other contender for the power pack is a British CV12 engine and a British transmission. The MBT80 will be a vehicle heavier than 60 US tons and longer than the XM1. The British are planning to decide on whether to use a British or American power pack by July 1979. The Project Manager MBT80 must make his recommendation by 31 March 1979.

2. In support of this decision, the British have asked for the loan of a turbine power pack in October 1979 under the terms of the ABCA agreement. They have also indicated a desire to purchase an additional power pack at some later date. The British have accepted the fact that they will make a decision on which power pack will be used in their MBT80 before they have any hardware to test. Because of this, complete answers to the questionnaire which they submitted in August are very important to them.

3. The British are interested in the AGT-1500 engine and X1100 transmission only. They are not interested in the accessories for the power pack such as cooling system, alternator, or hydraulic pump. They have stated their intentions as desiring the best power pack, either British or US, for their MBT80. They are not completely committed to standardization on either the engine or transmission. Their stated hope is that they would not have to change the engine configuration. They have stated that they would have to change the angle of the fan drive power takeoffs on the transmission to enable them to fit the cooling system into the narrower engine compartment of the MBT80. If the British were to make such a change internally to the transmission, this would destroy the commonality of transmission and therefore the British and US transmissions would not be interchangeable. If they could do it externally; for example, by a bevel gear set, the interface would not change and interchangeability would be maintained

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4. The British stated that they do not wish to be limited in their ability to unilaterally make design changes on either the engine or transmission once their firms have licenses to produce them. The conclusion from this is that standardization is a secondary aim behind obtaining what they consider the best power pack. It is very important that future negotiations establish the interfaces which will be maintained as common between British and American versions of the engine and transmission. Without this there is no assurance that the items will be interchangeable and that there will be any standardization between American and British engines or transmissions.

5. The ABCA agreements provide for loans of equipment from one country to another in the furtherance of standardization. Without a committment on Britain's part to maintain common physical, mechanical, and electrical interfaces on the engine and transmission, the ABCA agreements may not be appropriate for the loan of a power pack. The British presented a draft test program for the loan power pack. The loan would extend for two to two and a half years and consist of basic engineering tests of the power pack, steering and brake performance tests to the heavier MBT80 requirement, separate engine and transmission tests, and power pack tests to the MBT80 specification. Additionally, there would be a nine to twelve month period of reliability and durability testing to a duty cycle which has been defined for MBT80. The length and scope of this test program will necessitate upward revision of previous estimates of the cost of the loan turbine power pack and associated technical support and spare parts.

6. The unofficial test plan which I saw provided for the purchase of 21 more power packs in the 1980-1984 time frame. These would be tested by the British both in the laboratory and in various test vehicles.

7. On the second day I gave a brief report as to the status of the Automotive testing, the results, and a brief general description of turbine engine problems and solutions to those problems. Answers to the UK questionnaire were turned over to the British and they expressed general dissatisfaction with the scope of the answers. Chrysler and AVCO had provided some answers. Allison had refused, by letter, to answer any questions until a contractural relationship was established. The US position was explained which said that the scope of the British questions were such that they could not be fully answered by the contractors without additional funding and manpower. The British stated that the information requested in the questionnaire was the minimum essential which they needed to be able to make an evaluation and determination on the American powerpack. They expressed concern that they would not be able to get the answers to the questions when they visit the US in January and stated that they needed the answers by January in order to prepare their recommendations.

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8. The British trip to the US at the end of January was discussed. A tentative schedule is for the British to proceed first to Aberdeen to see the vehicle. They hope to be able to get on a vehicle, see a power pack pulled, etc. The next two days, the delegation would split and go to AVCO and Allison for detailed discussions with the contractors and answers to the remainder of their questionnaire. Two days would then be spent at the PMO and Chrysler and, after that meeting, two days would be spent back at the contractor, either AVCO or Allison, to obtain the remaining data which they required. Plans must be made to insure fullest cooperation from AVCO, Allison, and Chrysler and to insure access to the vehicle at Aberdeen.

9. In the afternoon, I had a meeting with several members of a Logistics Task Force headed by Colonel Glass. They were concerned with all areas of the supportability of the turbine power pack. I answered questions in a general way, provided what data I had, and stated that we would attempt to provide detailed answers to their specific questions as soon as possible. Members of the Logistics Task Force are scheduled to have a meeting with the PM and Chrysler at the same time as the technical people at the end of January.

10. The following possible problem areas exist in the provision of a power pack to the British in the time frame they require.

a. If the US decides to conduct DT/OT IIA,there is a strong possibility that power packs will not be available in the time frame required.

b. The scope of the British test program is such that it will be much more expensive than was forecast.

c. The British are not committed to standardization of engine and transmission. Therefore, the ABCA agreement may not be applicable for the loan of a power pack.

d. There is a competition for power pack and vehicle assets within the PMO. All vehicles are already committed to various uses after FSED. Some US requirements will not be met if a power pack is loaned to the UK.

11. The following recommendations are made:

a. That AVCO and Allison be informed of the intentions of the British and the importance of full responses to the questionnaire by the end of January when the UK delegation will visit them.

b. The US seek assurance from the UK that they will standardize on engine and transmission. Otherwise, the possibility should exist that the PMO be less involved in providing power packs to the UK.

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c. Provide a power pack to the UK in the October 79 time frame, if possible and desirable.

12. Based on Paragraphs 3 and 4, there appears to exist the strong possibility that the UK MBT80 will contain an engine and transmission similar to, but not interchangeable with, the engine and transmission of the XM1.

Paul M. Root
PAUL M. ROOT
Major, OrdC
Automotive Branch

Appendix G-3

Automotive Branch
MAJ Root/31231
26 July 1977

FACT SHEET

URCPM-GCM-SM

SUBJECT: German Unique Requirements for a Turbine Power Pack

Project Manager, XM1 Tank System

PURPOSE. To inform the Project Manager of the implications of the German Unique Requirements for the turbine power package.

BACKGROUND.
1. The PMO received a letter from Herr Jores dated 25 Jan 77, listing the German Unique Requirements for a Turbine Power Package. Jores stated that the requirements might have to be "supplemented or modified" as they found out more about the turbine. A reply was requested by the end of March 1977. The U. S. was prepared to discuss the Unique Requirements at the Working Group Meeting in early March. At that meeting, FRG had its turbine experts present, but Herr Bruns refused to discuss the requirements.

2. The PMO response was sent to FRG in early April, and the Unique Requirements are scheduled to be discussed at the September Working Group Meeting. PMO has requested the current German position on their Unique Requirements, in view of our response and the data they have received, prior to the September meeting so that it may be studied prior to the meeting. If a reply is not forthcoming, the unique requirements discussion should be postponed.

FACTS.
3. The XM1 turbine power pack can meet many of the unique German requirements. There are, however, a considerable number of requirements which are not currently met. They fall into two categories: The first is those requirements which the power pack will never meet due to its inherent design and performance characteristics, and the second is those which could be met with some modification to the existing power pack with associated cost impacts. Additionally, certain items need clarification or must be negotiated with FRG representatives before their impact can be determined.

4. The turbine power pack will not meet the following requirements:

Item	Reason
Cruising range of 500 KM (300 mi) with no additional fuel than that carried on Leo 2.	The turbine engine inherently has higher fuel consumption than the diesel. Using Leo 2 on board fuel,

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SUBJECT: German Unique Requirements for a Turbine Power Pack

Item	Reason
	range is estimated at less than 240 miles. Smaller turbine volume could allow for additional fuel. (Leo 2 did not meet this requirement during DT I testing.)
Fuel consumption rate to be same for turbine in Leo 2 as diesel. Fuel consumption for 24 hours. Battlefield day cannot exceed that for Leo 2 with diesel power pack.	Fuel consumption is inherently higher than diesel. This will never be met with the current engine.
Engine output and conditions. 1500 HP output when installed in vehicle.	Turbine engine is rated at 1500 HP gross. Effects of air cleaners, etc. will lower this when installed in vehicle. Magnitude of effect depends on particular system. US system rated at 1400 HP with air cleaners installed.
Growth potential to 1950 HP (30%).	1800 HP gross is the currently forecast growth potential without an extensive redesign of the engine and power pack.
Specific fuel consumption at various loads.	Turbine engine will not meet German requirements. Best turbine SFC is .475 lb/HP/hr at 80% load and the FRG worst specified is .477/lb/HR/hr.
MTBO of 600 hours when leaded gasoline is frequently used.	Will not be met. Extensive operation on leaded gasoline has detrimental effects on hot end components of engine, although rate of damage is not quantified.
Lubricants. Turbine must operate on motor oil or jet power plant oil.	Turbine is designed to operate on systhetic oil MIL-L-23699. Other oils are not suitable without redesign of the lubrication system.

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SUBJECT: German Unique Requirements for a Turbine Power Pack

Item	Reason
Brake System Requirements.	The turbine power pack does not have a hydraulic retarder and, therefore, probably will meet the requirements of the German Highway Traffic Licensing Code.
Power Pack installation without hull modification.	Power pack does not fit in Leo 2 hull. It is too long, the coolers interfere with the hull sides, and the transmission is too deep.

5. The turbine power pack could meet the following requirements with redesign and modifications to the existing configuration:

Item	Impact
APU required if idle fuel consumption higher than diesel. APU to be developed and funded by US.	Turbine idle fuel consumption is higher. APU could be developed. It would occupy volume currently taken by fuel, reducing cruising range. Development funding required.
Installation conditions: Turbine must be capable of being installed without modifying existing interfaces, including final drives.	Common final drive interfaces could be designed to be compatible with both XM1 and Leo 2. FRG has designed final drive adapter for turbine test rig.
Air inlet port as an integral part of power pack.	This is a vehicle configuration problem. Due to the size of the air cleaners, this is not recommended, although feasible.
Monitoring and governing equipment for the power pack.	These are basically vehicle-related instrumentation items that FRG could add if necessary.
Lubrication: Emergency lubrication for one minute.	This could be designed using cut-off valves or a redundant emergency oil system.

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Item	Impact
Chip detectors in lubricating system.	These are installed in prototypes and could be included in production engines.
Fuel system requirements	These are vehicle design requirements.
Electrical generator with 20KW output.	US alternator (650A) yields 18.2 KW. If 20KW were required, FRG could install their own generator in place of current one.
Power takeoff: Two required with output speed of 4000 RPM.	Engine currently has one PTO which drives accessories. Transmission has 3 PTO's: one drives alternator and two drive cooling fans. Additional ones could be designed in on transmission and output speed could be as required.

6. The following items need clarification before their impact can be determined:

Item	Reason
BRD must certify power pack ready for production	MOU states that the US will certify the power pack for production and provide it to FRG. Certification occurs at ASARC/DSARC III.
FRG reproduction rights.	FRG requires compensation if complete reproduction rights should not be possible. Statement is very vague.
Official verification by various FRG tests.	These types of tests are planned to be conducted by US and results will be provided to FRG. MOU states that US will conduct these tests.

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SUBJECT: German Unique Requirements for a Turbine Power Pack

Item	Reason
Productionalization proof by FRG by test.	FRG requires five complete power packs on loan to test. Packs are not planned for or funded. Earliest delivery in 1979. MOU states that US will certify that power pack is ready for production (ASARC/DSARC III). US could run additional tests if necessary to satisfy FRG.

DISCUSSION.
7. The Unique Requirements indicate that the Germans desire a turbine with all the performance and interface characteristics of their diesel--an impossible requirement. Depending on their true interest in the turbine, many of the unique requirements could disappear. If, on the other hand, they insist on the necessity of their requirements, they will never accept the AGT 1500 turbine power package.

8. Their most serious objections will probably be:

a. Fuel consumption and its ramifications.

b. Lack of a hydraulic retarder (an independent braking system) in the transmission.

c. Installation problems.

Appendix G-4

Automotive Branch
MAJ Root/31231
26 July 1977

FACT SHEET

DRCPM-GCM-SM

SUBJECT: Installation of Turbine Engine in Leo 2

Project Manager, XM1 Tank System

PURPOSE. To inform the Project Manager of the problems FRG faces in installing its AGT 1500 turbine power package in Leo 2.

FACTS.
1. The AGT 1500 turbine power pack will not fit in Leo 2 without hull modifications.

a. The power pack is too long for the hull. The air inlet extends through the bulkhead between the crew and engine compartments. Movement of the components located on the crew side of the bulkhead and other modifications would be necessary to accommodate the inlet and air plenum. It is not thought that the engine will interfere with the turret basket.

b. The lower outside corners of the oil coolers, which are mounted on the transmission, interfere with the hull. They are slightly too wide.

c. The transmission is too deep to fit in the Leo 2 hull. Modifications to the floor of the hull are required.

2. Herr Bruns asked, at a Working Group meeting in May, if the U. S. would modify the turbine to fit in Leo 2. It is not known if he was serious.

DISCUSSION.
3. The modifications required on the Leo 2 hull, while requiring some redesign, are not major and should be relatively easy if FRG is so inclined.

4. Other implications of the installation in Leo 2 include possible movement forward of the vehicle center of gravity due to the lighter turbine power pack and reduced vehicle cruising range, without the addition of more fuel, due to the turbine's higher fuel consumption.

CONCLUSION.
5. The U. S. position should be that we will assist the FRG in their efforts to install the turbine power pack in Leo 2, but will not and cannot modify the turbine power pack configuration to accommodate their vehicle.

Appendix G-5

MINUTES OF
US-FRG DISCUSSIONS CONCERNING THE
120MM TANK MAIN ARMAMENT PROGRAM
8, 9 AUGUST 1978, BONN

In furtherance of the spirit of cooperation, representatives of the US Government as represented by the Department of the Army (USDA) and the FRG Government, as represented by the Ministry of Defense (FMOD) held joint discussions on 8-9 August 1978 to clarify certain areas of mutual interest which would enhance joint efforts to achieve harmonization of the XM1 and Leopard 2 tank programs. Accordingly, the following discussions were held and the following agreements reached:

a. Consistent with the best interests and needs of the US Army and the implicit intent of the Harmonization Memorandum of Understanding, the USDA made a conscious decision to expedite the development and incorporation of the 120mm tank gun system into the XM1. It was agreed that the FMOD has met or is in the process of attempting to meet most of the US unique requirements. Some other US requirements may be classified as satisfied following further technical clarification which is on-going now. The USDA and FMOD further agreed that a limited number of the US unique requirements would be more appropriately and expeditiously addressed by the USDA. The US unique requirements in each category are listed at Inclosure.

b. The next item discussed was the FRG unique requirements for a turbine power pack. The USDA noted that since delivery of the FRG unique requirements, the USDA has taken cognizance of the FMOD concern that the turbine engine meet the FMOD performance and configuration requirements. The USDA and FMOD agreed that should the FRG adopt the turbine power pack, integration into the Leopard 2 tank system would be the responsibility of the FMOD just as responsibility for integration of the 120mm gun system into the XM1 has been accepted by the USDA as their responsibility. The FMOD is very interested to be precisely informed of the level of USDA fulfillment of Germany's unique requirements for the turbine power pack.

In the matter of turbine power pack performance requirements, the USDA updated previous correspondence and addressed the following items of FMOD concern:

(1) FUEL ECONOMY. The USDA has contracted for development of an auxiliary power unit which will significantly improve battlefield day fuel economy results. Additionally, the USDA is pursuing a fuel economy improvement program with a goal of reducing overall fuel consumption by at least 10%. However, the XM1 turbine is not expected by either country to equal the fuel economy required by the FRG requirements nor can it be so modified. The FMOD agreed to reconsider this ~~the necessity of their fuel economy~~ requirement after receipt of the data requested at paragraph b (4). The turbine power pack will use DF-2 (NATO F-54) as its primary fuel.

(2) GROWTH POTENTIAL. The USDA and FMOD currently have no requirement for an engine larger than 1500 HP for the Leopard 2 and

FMOD accepts 1500 HP in the series production type version of the LEO 2

the XM1. ~~Thus growth potential beyond 1500 HP is not an FRG requirement for the Leopard 2~~. Use of a turbine engine for other than main battle tanks can be a subject for follow-on discussions.

(3) BRAKE SYSTEM. As previously stated the US power pack has no redundant service brake system and cannot be so modified. However it is expected to meet all other FRG unique brake performance requirements. This fulfillment of braking performance will be proven by the USDA. As the redundant brake system is not possible in the current power pack, FMOD will seek a waiver as an exception to traffic law requirements as soon as FMOD can verify the braking performance demonstrated with an up-weighted FSED XM1 taking into consideration the main Leopard 2 aspects which are weight, center of gravity and sustained braking. FMOD noted that there is a precedent for waiver. FMOD agreed that, if a waiver is granted, the lack of a redundant brake system would not of itself block the introduction of a turbine power pack into production of Leopard 2.

(4) In the light of these agreements the target date of a German decision to adopt the turbine power pack for its Leopard 2 tank is the end of calendar year 1979. In order to meet this target date both parties agree to the following:

(a) The USDA agreed to provide expeditiously all background information and data relating to the FSED tests of the turbine power pack.

(b) The USDA agreed to provide expeditiously the detailed FSED test plans to facilitate possible incorporation of FMOD test requirements. Further, the USDA agreed that FMOD has the right to request minor changes to the tests, as they might occur, in order to satisfy FMOD test requirements. To the extent permitted by the XM1 test schedule, the USDA will attempt to incorporate those jointly agreed to changes.

(c) The USDA agreed to provide to the FMOD observer all test data on the turbine power pack as it becomes available.

(d) The FMOD stated that there will be no substantial redesign of the turbine power pack required to integrate the engine into the Leopard 2 tank. However, the USDA agrees to jointly explore means with the FMOD to minimize the impact of changes required to the Leopard 2 hull by incorporation of the turbine power pack. Possible cost questions for changes of mutual advantage will be addressed separately.

c. The USDA reported that US research and development efforts indicate that its planned advanced technology 120mm kinetic energy round can be made with interchangeable tungsten and depleted uranium penetrators. The FMOD expressed interest in the tungsten efforts for possible German application if the ammunition offers a substantial performance gain over the German 32mm penetrator and the ammunition can complete development by the 1982/1983 time frame. The FMOD and USDA agreed to form a Joint Working Group, under the GE-US Memorandum of Understanding of 15 December 1977 on Conduct of Joint Firing Tests, to review the US data base, consider joint and national activities on-going or planned, and recommend to national authorities by 1 November 1978 a proposed program which will permit the FMOD to decide whether or not to join the USDA in a cooperative development program. As a condition to a favorable decision, the US must initiate its 120mm XM1 program.

FOR THE FEDERAL MINISTRY OF DEFENSE:

RUNGE
MinDirig
UAL Rue VII
FMOD

Bonn, 9 August 1978

FOR THE US DEPARTMENT OF THE ARMY:

DONALD R. KEITH
Lieutenant General, USA
Deputy Chief of Staff for
Research, Development
and Acquisition

Bonn, 9 August 1978

APPENDIX H

Appendix H-1

MR TRAPP EWT
MG BABERS B
— Sam 14 MAR

DRCPM-GCM-SM 1 March 1979

GCM - SM
See Note
below

MEMORANDUM FOR RECORD

SUBJECT: Report on Trip to APG for OSD Engine Review Panel

1. On 28 February 1979 I participated in a demonstration of the XM1 tank for the OSD Engine Review Panel. The demonstration was held at H field, lasted from 0845-1200 and consisted of:

a. Firing demonstration of the XM1 and M60A1 RISE (passive) over the bump course.

b. Firing of the XM1 smoke grenades and demonstration of the smoke generator.

c. Riding in and driving the XM1 and M60.

d. Display of the power pack removed from the vehicle, the engine compartment and ground hop of the power pack.

2. The demonstration went extremely well and was well received by the panel members. They were impressed with the firing demonstration and comparative mobility of the XM1.

3. The display of the power pack went very well also. There was great interest in the pack, its installation, the plenum seal and air cleaners and other interfaces. The engine fuel control system was explained and there were many other questions. The most significant are:

very well done! B

a. Tracking of modules by serial number (a recurring question). With the modular maintenance concept, the Army may have to track modules during production and identify them separately in the logbook.

b. Inlet/air induction system icing tests. Messrs. Neumann and Horan firmly believe that the air cleaner V-packs and FOD screen will ice under certain circumstances. PMO should probably conduct icing tests on an engine during the fall of 1979 to answer this question. Mr. Neumann unofficially offered General Electric's environmental facilities for this test.

any reason we should push this? what does AVCO/chrysler have to say?

DRCPM-GCM-SM 1 March 1979
SUBJECT: Report on Trip to APG for OSD Engine Review Panel

4. I believe the demonstration had a very positive benefit and was invaluable in helping the panel to understand the program, the tank and the power pack.

5. The RAM assessment group of the panel is tentatively scheduled to meet at Anaheim, California, on 2 March and again on 8 March. They will have no new data to analyze at these meetings, only that which was provided at previous meetings, and consequently may not contribute much new to the program.

6. The engine design group is scheduled to go to AVCO 14-16 March. Dr. Petrick is scheduled to go to Allison 7 March.

7. There is a panel meeting scheduled in Los Angeles 19-20 March, presumably to draw up conclusions.

Paul M. Root
PAUL M. ROOT
Major, OrdC
Automotive Branch

Appendix H-2

XM1

MAJ ROOT

Briefing to OSD Panel
at AVCO

28 JAN

ENGINE DURABILITY

STATUS

XMI

OUTLINE

- FEB 79 STATUS
- OSD PANEL FINDINGS
- TEST PLAN
- STATUS
- RESULTS AND CONCLUSIONS

ENGINE STATUS

FEB 1979

- INTENSIVE TESTING- 50,000 MILES
- FIELD FAILURES
- NOT MEETING DURABILITY GOALS
- MANY FIXES UNDER TEST, SOME NOT
- VARIOUS ENGINE CONFIGURATIONS IN FIELD

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AREAS OF CONCERN ON ENGINE

OSD PANEL REPORT - APRIL 79

- LOW PRESSURE TURBINE WHEEL REDESIGN
- AIR INDUCTION SYSTEM
- COMPRESSOR SURGE MARGIN
- COMBUSTOR COKING - TURBINE NOZZLE AND BLADE EROSION
- BEARING COKING
- HIGH AND LOW PRESSURE TURBINE NOZZLE CRACKING
- ACCESSORY GEARBOX FAILURE - #13 BEARING
- SCROLL BURNOUT
- COMBUSTOR LINER DURABILITY

NOTE: SOME FIXES WERE ALREADY UNDER TEST WITH VARIOUS AMOUNTS OF MILEAGE

TEST PLAN

VEHICLE

TYPE TEST	LOCATION	ASSETS	DURATION	ENGINE CONFIGURATION
DURABILITY	FORT KNOX	3 TANKS	6000 MILES EACH	ZERO TIME
AIR INDUCTION	WSMR	1 TANK	1200 MILES	FSED

LABORATORY

TYPE TEST	LOCATION	ASSETS	DURATION	ENGINE CONFIGURATION
EXTENDED DURABILITY	AVCO	2 ENGINES	400 HR NATO 600 HR MISSION PROFILE	1 USED AND 1 NEW PRODUCTION PROTOTYPE (FSED)

NOTE: ALL ZERO TIME AND EXTENDED DURABILITY ENGINES OF LATEST CONFIGURATION AND

INCORPORATE CORRECTIVE ACTIONS IN AREAS IDENTIFIED BY OSD ENGINE COMMITTEE.

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OTHER AVCO FSED TESTING

- 3RD 400 HOUR NATO TEST ON ENGINE 49
- 2000 CYCLE LOW CYCLE FATIGUE TEST
- ENVIRONMENTAL AND ABUSIVE TESTS

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FORT KNOX TESTING

GOAL: 3 VEHICLES 6000 MILES EACH

STATUS: COMPLETE

ENGINE USAGE: 4 ENGINES

	# 33	# 47	# 50	# 51
HOURS	268	686	463	454
MILES	2862	6547	4678	3748

FORT KNOX ENGINE REMOVALS

			MILES AT REMOVAL			
DATE	ENGINE	VEHICLE	SINCE LAST INSTALLED	REASON	CAUSE	DURABILITY
27 JUN	47	P2	1204	FOD	FOD SCREEN MOUNTING BOLT	NO
13 AUG	50	P7	2437	FAILED #3 BEARING	OIL COOLER CONTAMINATION	NO
23 AUG	33	P5	2641	PRECAUTION	OIL COOLER CONTAMINATION	NO
8 SEP	33	P5	48	FAILED #3 BEARING	IMPROPER ASSEMBLY	YES
25 SEP	33	P5	173	FAILED #12 BEARING	UNDERSIZED PILOT RING-QUALITY	YES
			MODULE EXCHANGE			
26 SEP	51	P7	1271	OIL LEAK	FRONT MOUNTING PIN - IMPROPER REPAIR	NO

AIR INDUCTION TEST

WSMR

GOAL: 1 TANK - 1200 MILES OF OPERATION IN HEAVY DUST TO VERIFY PRODUCTION AIR INDUCTION SYSTEM

STATUS: 1300 MILES - NO PROBLEMS - TEST COMPLETE

ENGINE WILL BE CALIBRATED AND INTERNALLY INSPECTED AT END OF TEST TO DETERMINE CONDITION.

NOTE: MUCH OPERATION AT FORT KNOX WAS ALSO UNDER HEAVY DUST CONDITIONS.

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1000 HOUR TEST

TYPE - DURABILITY -

- 400 HOUR NATO CYCLE TEST FOLLOWED BY 600 HOUR MISSION PROFILE TEST

PURPOSE -

- DEMONSTRATE DESIGN MATURITY
- IDENTIFY DURABILITY LIMITERS
- SEVERE OVERTEST OF ENGINE (17,000 - 21,000 MILE EQUIVALENT)

DURATION - 1000 HOURS

ENGINE	TEST HOURS	INCIDENT	INCIDENT HOURS	CAUSE	RESOLUTION
# 52	1000	HP TURBINE BLADES REPLACED	492	POSSIBLE STRESS-RUPTURE PROBLEM	NO ACTION REQ'D AVCO ANALYSIS REVEALED NO PROBLEM
	(1387 TOTAL HOURS)	1 ST POWER TURBINE WHEEL REPLACED *	492	POSSIBLE LCF PROBLEM	CHANGE FILLET RADIUS ON BALANCING DISC
		HP NOZZLE REPLACED	642	NOZZLE CRACKING AND BURNING	LOWER MAXIMUM TEMP
		1 HP TURBINE BLADE REPLACED	825	RETENTION WIRE SHRANK - BLADE MOVED REARWARD	CHANGE DIMENSIONS OF RETAINING WIRE CHAMFER MOUNTING GROOVE
		COMBUSTOR CURL, BURNED - COOLING HOLES BLOCKED	902	IMPROPER ASSEMBLY	IMPROVE QUALITY CONTROL
		#3 BEARING OUTER RACE SPUN	923	LOSS OF PRESS FIT	PIN BEARING RACE

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LAB TESTING - 1000 HOURS

ENGINE	TEST HOURS	INCIDENT	INCIDENT HOURS	CAUSE	RESOLUTION
# 53	1000	# 10 SEAL SEEPED	264	UNKNOWN	REINSTALLED
		# 10 SEAL REPLACED	433	OIL LEAKAGE	
		RECUPERATOR CORE BURNED	673	UNDER INVESTIGATION	
		4 BRG & SEAL REPLACED	755	SEAL HUNG UP UNDER INVESTIGATION	

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TEST RESULTS

- VEHICLE AND LABORATORY TESTING SUCCESSFUL

- NO RECURRENCE OF PROBLEMS IDENTIFIED BY OSD PANEL

MINIMUM EXPERIENCE	3011 HOURS; 18,094 MILES ON FIXES
AIR INDUCTION SYSTEM	19,300 MILES

- NEWLY UNCOVERED PROBLEMS MINOR

  CORRECTIVE ACTION UNDERWAY

CONCLUSION

- ENGINE DURABILITY IS MEETING ITS REQUIREMENT

- ENGINE DESIGN IS READY FOR PRODUCTION

Appendix H-3

OPM XM1 COMMENTS
GAO REPORT 951482

Page 5 - Comment 12

Allegation: Inadequate design of internal engine components, such as the LP turbine wheel and (LP) turbine nozzle caused an engine failure and caused other engines to stop functioning properly.

PM Status Comment: The statement is misleading, inaccurate and should be deleted. The engine design has never proven to be faulty. Some design changes were made as required due to problems revealed by testing, but this is normal in an engine development program. One component (low pressure turbine wheel) was made of a material used in other turbine engines by a standard process but proved to be inadequate for the type of duty cycle to which the engine was subjected. A tank-type mission is new for a turbine, and the properties of this material (C101) were not known by anyone to be sensitive to the particular cycle prior to the testing. Only one engine was damaged by this. A redesign of the low pressure turbine wheel has been incorporated and completely successful in extensive vehicle and laboratory testing.

A quality - not design - defect in the LP turbine nozzle caused problems in two engines. The cause was determined, all engines were checked for the problem and all nozzles now have an inspection to prevent recurrence of the problem.

OPM XM1 COMMENTS
GAO REPORT 951482

Page 6 - Comment 13

Allegation: Range dropped from 270 to 246 miles with increased track tension - a 10% increase in fuel consumption.

PM Status Comment: It is premature to conclude that the range has decreased. Based on testing, the increased track tension does increase fuel consumption by about 10%. An additional test was conducted in December 1979 with the increased track tension which yielded a range of 270 miles; i.e., no decrease in range. This scatter in the data is due to a number of variables and fuel consumption and cruising range tests will be repeated in DT III to verify the range of production tanks.

OPM XM1 COMMENTS
GAO REPORT 951482

Page 6 - Comment 14

Allegation: No successful cold starts at -25^{o}F. Procedures differed from TECOM's.

PM Status Comment: Problem was due to low battery voltage during initial inrush at starter tripping the ECU protective circuitry. It had nothing to do with the engine's inherent ability to start at cold temperatures.

Chrysler is correcting this problem by providing a separate ECU battery which will provide power to the ECU during starts. A conceptual version of this was used at the Eglin Cold Room and resulted in repeated successful starts. The Eglin test was a contractor test and not a TECOM test.

TECOM has been asked to develop reasonable Test Operating Procedures (TOP) for a ground turbine engine and to clarify its interpretation of its TOP.

OPM XM1 COMMENTS
GAO REPORT 951482

Page 11 - 2d Paragraph Up

Allegation: Extraordinary maintenance actions were taken to keep test on schedule. Fuel nozzle cleaning at 25 hr intervals is cited as example.

PM Status Comment: Maintenance was in accordance with manuals and Army procedures and performed on a third shift basis to expedite completion of the test. Details should come from SP.

During Ft. Knox Phase I testing, production configuration fuel nozzles were not yet available. Recognizing that the nozzle did not meet the requirements, a 25 hour inspection and clean-as-necessary program was instituted to avoid needless combat mission failures.

At the end of Phase I and during Phase II, production fuel nozzles were used. Since they were so new and no information was known of their coking rate, they were inspected every 25 hours, but cleaned only if there was a failure to start. One nozzle failed to start at 133 hours (due to the driver not allowing the start sequence to be fully completed), was cleaned and then ran over 150 hours the requirement. Another went 178 hours, and the third has over 340 hours (in several engines) without requiring cleaning. This is a good demonstration of the 150 hour semi-annual cleaning requirement.

OPM XM1 COMMENT
GAO REPORT 951482

Page 13- Paragraph 2

Allegation: Engine has not met its required reliability and durability goals.

PM Status Comment: Engine has no required reliability and durability goals. Its reliability is evaluated as part of the XM1 Tank System and its durability is evaluated as part of the power train.

Based on Ft. Knox testing, the XM1 exceeds its requirements.

	Requirement	Demonstrated
Combat Mission Reliability	272 MMBF	299 MMBF (Phase I)
Power Train Durability	.5/4000	.54/4000 (Phase I & II)

OPM XM1 COMMENT
GAO REPORT 951482

Page 14 - Paragraph 3

Allegation: As of April 1979, engine's demonstrated reliability and durability were so low that they could be doubled and still fall short of its goals. Recent testing tends to confirm this assessment.

PM Status Comment: Based on Ft. Knox testing, the vehicle reliability and power train durability requirements have been exceeded.

Chrysler has apportioned reliability to components based on a design objective of 360 MMBF for Combat Missions as a goal and has included an engine durability number in the Chrysler contract with AVCO, but these are not government requirements. The engine is close to meeting those levels of reliability and durability.

There were optimistic goals between the contractor and its subcontractor and are not government requirements.

The demonstrated improvement in these areas can be seen by comparing the results of the OSD Panel's assessments in April 1979 and January 1980 and the PMO's evaluation of Phase I and II Ft. Knox testing.

Powertrain
Demonstrated Combat Mission Reliability Assessment

	Panel Evaluation April 1979 (MMBF)	Panel Evaluation January 1980 (MMBF)
TOTAL POWER TRAIN	360	2,591
- Engine	470	2,975
- Transmission	2,090	20,082
- Final Drive	5,230	-1/
- Other Power Train	-	-1/

1/ No failures in Phase I testing.

Demonstrated Power Train Durability

	Panel Evaluation DT/OT II April 1979 (MMBDF)	Panel Evaluation Phase I-Ft. Knox January 1980 (MMBDF)	PMO Evaluation Phase I & II - Ft. Knox January 1980 (MMBDF)
POWER TRAIN	2,460	4,820	6,400
- Engine	3,140	6,020	8,000
- Transmission	11,000	24,100	32,000
- Final Drive	-	-1/	-2/

1/ No failures in Phase I testing.
2/ No failures in Phase I or II testing.

OPM XM1 COMMENT
GAO REPORT 951482

Page 14 - Last Paragraph

Allegation: GAO states the OSD Panel compared engines demonstrated durability and reliability against established requirements.

PM Status Comment: They compared the engine against contractor established goals, not government requirements.

See previous comment.

OPM XM1 COMMENT
GAO REPORT 951482

Page 15 - Charts

Allegation: Chart showed only April 1979 OSD Panel results.

PM Status Comment: Results of recent OSD Panel study for engine durability and reliability are provided.

UPPER CHART

ENGINE	Design Objective (Note a) (MMBF)	Panel Assessment (Note b) (MMBF)	January 1980 Panel Assessment (Note c) (MMBF)	January 1980 PMO Assessment (Note d) (MMBF)
Durability	10,000	3,160	4,820	6,400
Reliability:				
System	2,825	420	2,975	3,168
Mission	5,000	470	2,975	3,168

a/ Design objectives as set forth in the engine manufacturer's contract.

b/ Assessment based on available test data with testing about 60 percent completed

c/ Phase I Ft. Knox test results.

d/ Based on Phase I and II Ft. Knox test results. There were no additional power train durability failures during Phase II.

LOWER CHART

ENGINE	Design Objective (MMBF) (Note a)	April 1979 Demonstrated Performance (MMBF) (Note a)	April 1979 Panel's Projected Performance (MMBF) (Note a)	January 1980 Demonstrated Performance (MMBF) (Note b)	January 19 Panel's Projected Performanc (MMBF)
System Rel.	2,825	420	860	2,975	15,061
Mission Rel.	5,000	470	1,050	2,975	15,061

a/ Mean miles between failure.

b/ Phase I Ft. Knox test results

OPM XM1 COMMENT
GAO REPORT 951482

Page 16 - Comment 33

Allegation: One engine completed the 1000 hr test. Parts were replaced to avoid possibility of engine damage. The second test is underway.

PM Status Comment: Update: Both tests have been completed. PMO considers the tests as extended durability tests and that they were successfully completed. The purpose of such testing is to identify those components which might limit engine durability at high engine operating times. The tests did this, some parts were replaced. A PIP program is being structured to increase the life of the durability-limiting parts.

OPM XM1 COMMENT
GAO REPORT 951482

Page 16 - Comment 34

Allegation: Six engines were replaced during 12,000 miles of test for all reasons, yielding 2,000 MMBF (all failure causes).

There were two inherent design failures for a 6000 MMBF for durability failures.

PM Status Comment: Update: During Phase II of the Ft. Knox testing, there were no more engine removals so the numbers become:

2,666 MMBF (all failure causes)

8,000 MMBF (durability failures)

The two durability failures were from errors during assembly, not design problems. Inspection procedures have been incorporated into the engine build procedures to avoid these problems in the future.

Appendix H-4

DRCPM-GCM-SM POINT PAPER Automotive Branch
MAJ Root/31231
3 March 1980

TOPIC	DISCUSSION POINTS
Why should Congress believe OSD/BRP instead of GAO?	
0 Membership/qualifications.	0 OSD Panel consisted of high ranking turbine engine and RAM-D engineers from government and industry.
	0 Engines were inspected by engineers from Navy Air Propulsion Center for OSD Panel.
	0 GAO Panel contained no turbine engineers (or any type of engineers?).
	0 GAO conducted no engine inspection with with qualified engineers.
0 Scope of review.	0 OSD panel conducted comprehensive reviews in Feb-Apr 79 and Dec 79-Feb 80.
	0 OSD panel used results of recent Ft. Knox and engine lab testing.
	0 GAO did not use recent lab test results.
0 Yardstick.	0 OSD Panel evaluated against government vehicle and power train reliability and durability requirements.
	0 GAO evaluated against engine design goals (not government requirements).
0 Recommendations	0 OSD Panel made specific recommendations to further improve engine.
	0 GAO recommendations concerned only limitation of production and alternate engines.

VITA

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Mr. Root was born on February 1, 1944, at Santa Barbara, California. He is the son of Paul and Marylou Root of Carmel, California. His wife is the former Paddy O'Kelly, and they have five children between them.

Mr. Root graduated from Punahou School in Honolulu, Hawaii, in 1962. He received a Bachelor of Science degree from the United States Military Academy in 1966 and a Master of Science degree from Stanford University in 1969. He is a graduate of the British Royal Armour School Long Armour Infantry Course, the Command and General Staff College of the US Army, and the Defense Systems Management College.

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